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Analysis of the Spatial Dynamics of the American Lobster (Homarus Americanus) Fishery along the Coast of Maine

Kevin M. Scheirer

ANALYSIS OF THE SPATIAL DYNAMICS OF THE AMERICAN LOBSTER (HOMARUS AMERICANUS) FISHERY ALONG THE COAST OF MAINE

By

Kevin M. Scheirer

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Advisory Committee:

Yong Chen, Assistant Professor for Fisheries Population Dynamics, Advisor

James A. Wilson, Professor of Marine Science

Robert S. Steneck, Professor of Marine Science

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An Abstract of the Thesis Presented
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The American lobster (*Homarus americanus*) supports the most valuable commercial fishery in the northeastern United States, thus the fishery is critical to Maine's economy. No systematic study has been done to collect information about, identify, and quantify the spatial dynamics of the Maine lobster fishery. This project helps to provide a better understanding of Maine's lobster fishery dynamics, and it will aid future efforts to improve the stock assessment of Maine's lobster fishery. The analysis consists of three distinct parts: (1) comparison of data collected by two separate fishery dependent sampling programs; (2) spatial analysis of electronic logbook data; and (3) harbor gang territoriality evidenced by electronic logbook data.

The Maine Department of Marine Resources has established two fishery-dependent sampling programs: sea sampling and port sampling. Using data from 1998 – 2000, we evaluated the consistency in size composition and catch per unit of effort

(CPUE) between the sea and port sampling programs. The overall pattern that emerged was a stronger relationship between sea and port sampling data over time from 1998-2000, implying the two sampling programs were consistent in describing temporal variations in CPUE. This study suggests that either program should be sufficient in monitoring temporal trends of the lobster fishery.

The American lobster fishery exhibits strong seasonal variations in spatial distributions of traps. In this study, we developed and applied two spatial statistical models, a moving window model and the empirical distribution function (EDF) model, to explore and describe data from the lobster fishery in order to quantify the spatial and temporal dynamics of fishing effort. This study suggests that fishing effort data were clustered rather than randomly distributed for the entire fishing season in the Stonington area. Therefore, we can state the data are not random in space or in time, but rather trap locations are clustered. Plots of nearest trap locations from May to December indicated that the trap locations were also not random at the smaller time scale. The nearest location distances of trap locations varied by month, but a general trend of decreased distances from May to September was observed, followed by increased distances from October to December.

Electronic logbook data were displayed using GIS software to analyze the various boundaries observed by lobstermen. Management zone boundaries affected Stonington, Vinalhaven, Tenants Harbor, Spruce Head, New Harbor, and Long Island fishing areas to varying degrees in most seasons. Unofficial or territorial boundaries were assumed to have affected all areas, but some more obviously than others. Among these most affected were Stonington, Tenants Harbor, Port Clyde, Metinic, Round Pond, New

Harbor, Cousins Island, and Harpswell. Territoriality among harbor gangs was shown to have at least partially structured the fishing areas observed through Thistle Marine data.

These analyses have provided the DMR with important information on their current sampling programs, methodologies for future analysis of the fishery, and information affecting future management decisions and stock assessments.

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Chapter 1

INTRODUCTION

Maine Lobster Fishery Characteristics

The American lobster (*Homarus americanus*) is distributed throughout the northwest Atlantic from the Straight of Belle Isle, Newfoundland to Cape Hatteras, North Carolina from mean low water to depths of 700 m (Cooper and Uzmann, 1980; Lawton and Lavalli, 1995). It supports the most valuable commercial fishery in the northeastern United States (ASMFC, 2000), with ~75% of the fishery value derived in Maine (CITATION). Thus the fishery is critical to Maine's coastal economy and culture. Recent annual landings of over 50 million pounds by more than 7,000 commercial licenses in Maine illustrate the importance of this fishery. License holders make large investments in time, boats, and gear. Many full time lobster fishermen have spent half or more of their lives lobstering, paid upwards of $200,000 for boats, and fish 600 to 800 wire traps which can cost more than $60,000 with the necessary tackle and conservation measures. They operate from diesel powered boats averaging thirty-five feet in length, fish traps three to four feet long, use mainly herring for bait, and use color-coded styrofoam buoys to mark their trap locations (Acheson and Brewer, 2003).

The face of the lobster fishery has changed dramatically over the last thirty or forty years. Gear improvements and electronic technology have changed the way lobsters are caught and the effort put into catching them. For instance, wire traps have replaced wooden traps, and hydraulic haulers, chart plotters, and echosounders have become standard equipment on many boats as the fishery has progressed over time. There are many conservation measures that have been adopted since the early 1900's. The primary laws that affect which lobsters are harvested include the double gauge law that protects juvenile and large lobsters, a prohibition on taking egg-bearing females, and the v-notch law to protect female lobsters. Gear related measures include the escape vent law to allow small lobsters to exit traps, capture by trap only (no diving or trawling), trap runner limits, and whale entanglement "weak links" for offshore gear. New modifications to the type of warp used between traps are in the process of being implemented, with the commonly-used float warp being replaced with a modified float/sink warp to reduce whale entanglement.

Lobster Fishery Data

Optimal management of coastal Maine's lobster stock requires complete understanding of its population dynamics. The quality of its assessment is thus a central issue in lobster fishery management. Of the factors that may affect the quality of the lobster stock assessment, fisheries data is one of the most important because these data are utilized in lobster stock assessment models. Fisheries scientists and managers use fishery-dependent sampling programs as a means of monitoring the commercial fishery and collecting fisheries data for stock assessment and management. The benefits of such programs include greater quantities of data and lower costs compared with fisheries-independent sampling programs. Large and diverse amounts of data must be collected from multiple sources to ensure the quality of fisheries stock assessments. Conversely, limited data may introduce large uncertainties and biased errors in stock assessment, potentially resulting in the mismanagement of a fishery (Walters, 1998; Chen and Rajakaruna, 2002).

Fisheries data are often collected by monitoring programs such as port and sea sampling programs and logbook systems (Hilborn and Walters, 1992). Common measurement variables often include catch, measures of fishing effort, length, weight, and fecundity information. Variables measured often differ between sampling programs due to sampling design, the nature of the program (on-board a vessel, dockside, or electronic), or other constraints such as budgets, logistics, and governmental management rules. Multiple sampling programs allow several unique sampling designs that can measure the characteristics of the fishery at the different temporal and spatial scales that the manager wishes to monitor. Comparative study of these sampling programs may also help identify industry fishing behavior. For example, the comparison of sea and port sampling is useful in detecting fleet responses to changes in regulations. Problems, however, may arise when data from the programs characterize the fishery in significantly different ways. The programs may not show the same trends, their data may disagree on important variables such as catch, effort, or length frequency; or temporal and spatial trends may be different. In this case, choices may need to be made as to what data source is most reliable and desirable in describing the fishery. This may often depend on sampling design, costs, quality and quantity of data, and temporal and spatial coverage of the sampling programs.

Chapter 2

SPATIAL AND TEMPORAL COMPARISON OF CPUE AND SIZE FREQUENCY FROM SEA AND PORT SAMPLING PROGRAMS

Chapter Abstract

The American lobster (*Homarus americanus*) supports the most valuable commercial fishery in the northeastern United States, thus the fishery is critical to Maine's economy. In order to better manage this important fishery, the Maine Department of Marine Resources has established two fishery-dependent sampling programs: sea sampling and port sampling. However, the use of two different data sources has raised concerns about whether this approach is consistent and accurate. Using data from 1998 – 2000, we evaluated the consistency in size composition and catch per unit of effort (CPUE) between the sea and port sampling programs. The strength of the statistical correlations between the two sampling programs varied depending upon the measure of CPUE, sampling year, and whether time or area was the comparison variable. The overall pattern that emerged was a stronger relationship between sea and port sampling data over time from 1998-2000, implying the two sampling programs were consistent in describing temporal variations in CPUE. However, county CPUE estimates between the two programs were significantly different in all three years. This suggests an inconsistency between the two programs in describing spatial variations in CPUE. Size composition reported by the two programs was very similar with significant differences in only three months out of the twenty-one tested. This study suggests that either program should be sufficient in monitoring temporal trends of the lobster fishery.

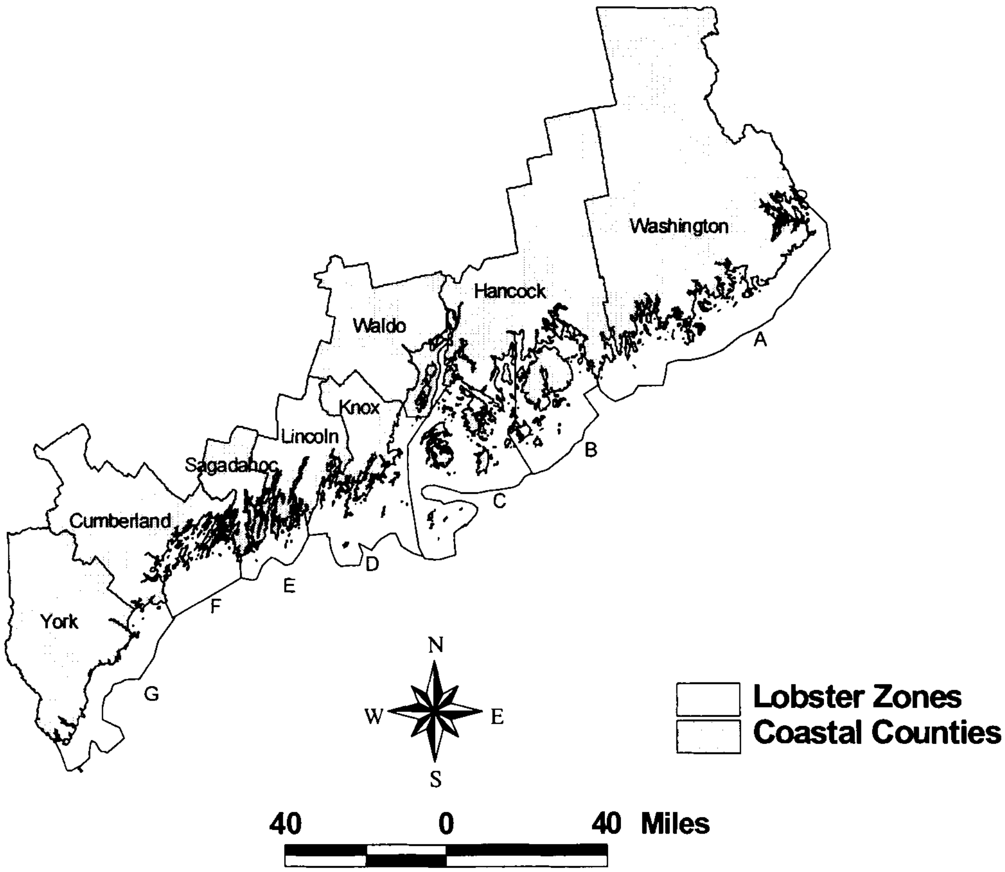
Introduction

In order to have extensive spatial and temporal coverage of data collection for better management of the lobster fishery, the Maine Department of Marine Resources (DMR) has established two fisheries-dependent sampling programs. The port sampling program has been in place since 1967, and it has supplied fishery managers with large amounts of data on the lobster fishery including catch, various measures of fishing effort, and biological information about landings. The sampling design is random (i.e., the number and location of sampling events are chosen randomly). Lobster dealers who buy from five or more boats are included in the sample set, and ten of these dealers per month are randomly selected as sampling locations. These samples are representative of the distribution of dealers in the seven coastal counties in Maine (Wilson et al., 2001; Figure 2.1.). DMR biologists draw random samples of lobsters from each boat as it arrives at the dealer's wharf, and usually more than one boat is sampled per sampling trip. The sample design remained largely unchanged until 2000, when sampling time was expanded from April through December to the entire year.

The sea sampling program, which places DMR biologists on commercial fishing boats to record lobstermen's catch and sample for biological information, has been in place since 1985. The Maine coast is divided into seven lobster management zones (Fig.2.1.). From 1998 through 2000, sampling efforts were greatly increased to cover more boats and more fishing time. Currently three sampling trips per month are planned for each zone, totaling a possible 21 trips per month from May to November (Wilson et al., 2001). One boat per trip is sampled, and because fishermen voluntarily allow sampling on their boat, most boats are sampled more than once in a season. It is more efficient to make return trips with a cooperative fisherman than to convince another fisherman to allow state biologists on board. The increase in effort in the sea sampling program since 1998 has provided a more comprehensive and detailed coverage of the Maine lobster fishery.

As a result of the expansion of effort and increases in the costs of the sampling program, a comparative analysis was needed for evaluating differences in the data collected from the two sampling programs. Of key interest were CPUE and size composition estimates as well as the overall scale of sampling and data collected, which are essential in assessing and monitoring the lobster stock and developing management plans for the lobster fishery in the state of Maine. Such a study will indicate if the data collected from the two sampling programs consistently described Maine's lobster fishery. A consistent pattern would allow us to combine the two programs and use limited financial resources more efficiently to have greater spatial and temporal coverage of the fishery in fishery-dependent sampling. An inconsistent pattern in describing the lobster fishery, however, would require us to identify factors that result in the differences in the two sampling programs. Using data from 1998 –2000, we evaluated the consistency in size composition and CPUE between the sea and port sampling programs. Because there are many measures of fishing effort in each sampling program, we also compared CPUE using different measures of catch and effort for each sampling program.

Figure 2.1. Maine Counties and Lobster Management Zones.



Methods

The port and sea sampling programs were compared using data from 1998 to 2000 because the sea sampling effort was initially expanded in 1998 and continued expanding through 2000. Also, the analysis was limited to the months from May to November by the duration of the sea sampling program season. Five different measures of CPUE were calculated for each sea and port sampling trip: pounds per trap haul (lbs/th), pounds per trap haul set-over-day (lbs/thsod), number per trap haul (num/th), number per trap haul set-over-day (num/thsod), and number per boat hour (num/bh). Pounds (lbs) are the pounds of legal lobsters landed, and numbers (num) are the number of legal lobsters landed. Trap hauls (th) are the number of traps that a lobsterman pulls out of the water in one trip. Set-over-days (sod) are the number of days that a trap has been fished without being checked (generally one to ten days). Trap haul set-over-days (thsod) are calculated by multiplying the number of trap hauls by the number of set-over-days for that group of traps (i.e. 300 trap hauls multiplied by 5 set-over-days equals 1500 thsod). The sum of the catch for each sampling trip was divided by the sum of the effort for each sampling trip (example in Table 2.1.). The mean, median, and coefficient of variance (standard deviation/mean) were calculated for each year from the sampling trip CPUE's (Table 2.2.).

Table 2.1. Example calculation of five measures of catch-per-unit of effort (CPUE)

CPUE Measure	Numerator	Denominator	CPUE
Number/Trap Haul	303	885	0.34
Number/Trap Haul Set-over-day	212	640	0.06
Number/Boat Hour	122	9.75	12.51
Pounds/Trap Haul	255	765	0.60
Pounds/Trap Haul Set-over-day	569	406	0.07

Table 2.2. Statistics for five measures of CPUE from Port and Sea Sampling: 1998-2000

CPUE Measure	Summary Statistic	1998		1999		2000	
		Port	Sea	Port	Sea	Port	Sea
Number/ Trap Haul	Mean	0.87	1.18	0.86	1.12	1.02	1.45
	Median	0.87	1.01	0.81	0.88	1.00	1.30
	CV	0.54	0.74	0.52	0.70	0.55	0.64
Number/ Trap Haul Set-over-day	Mean	0.22	0.25	0.19	0.21	0.24	0.29
	Median	0.20	0.23	0.19	0.19	0.20	0.24
	CV	0.91	0.65	0.53	0.68	0.65	0.75
Number/ Boat Hour	Mean	21.21	30.84	21.31	28.57	24.73	33.78
	Median	21.05	27.27	19.77	22.62	21.69	29.90
	CV	0.56	0.67	0.54	0.72	0.60	0.68
Pounds/ Trap Haul	Mean	1.08	1.49	1.07	1.44	1.30	1.88
	Median	1.06	1.27	1.01	1.16	1.25	1.65
	CV	0.53	0.76	0.52	0.69	0.56	0.68
Pounds/ Trap Haul Set-over-day	Mean	0.27	0.32	0.23	0.28	0.30	0.39
	Median	0.24	0.28	0.24	0.25	0.25	0.31
	CV	0.94	0.65	0.53	0.68	0.66	0.77

It was unclear as to whether pounds or numbers was a more appropriate measure of catch when being used to compare two different data sets. In order to answer this question, CPUE was calculated using pounds and numbers needed to be compared within the sea and port sampling data sets. Because the total number of pounds of lobster and the total number of lobsters sampled each trip are different (e.g. 300 lobsters weighing a total of 450 pounds) the five measures of CPUE were standardized for both port and sea sampling data sets from 1998-2000. The standardization consisted of subtracting the mean CPUE (calculated from the sampling trip CPUE's) from each sampling trip CPUE and dividing that number by the standard deviation (calculated from the sampling trip CPUE's). This standardization gave the two sets of CPUE the same scale (amount of variation around the mean), making them comparable.

A regression analysis was performed for mean lbs/th vs. mean num/th for each year within both sea and port sampling data sets. If all the regression models have a slope estimate not significantly different from 1, an intercept estimate not significantly different from 0, and an r^2 greater than 90%, then catch estimates from pounds or numbers of lobsters do not significantly differ.

The comparison of port and sea sample CPUE's was conducted on a monthly time scale, using May to November for each sampling program. The time frame of a month was used because it averaged out the differences in sampling techniques (both in number of boats sampled per trip and number of trips per month) and would preserve a certain amount of variation over time. There were more sea sampling trips than port sampling trips, but port sampling collected data for more boats than sea sampling (Figures 2.2. and

2.3.). The mean monthly CPUE's were calculated using the sampling trip CPUE's (mean of sampling trip CPUE's in each month).

A regression analysis was conducted with the port sampling CPUE as the independent or X variable and the sea sampling CPUE as the dependent or Y variable. The measures of CPUE used in the regression analysis were num/th, num/thsod, num/bh, lbs/th, and lbs/thsod. The monthly means of the sampling trip CPUEs were plotted in one regression per year per measure of CPUE, totaling fifteen regression analyses (five regressions for 1998, 1999, and 2000).

Figure 2.2. Comparison of yearly sampling effort between sea and port sampling in number of sampling trips.

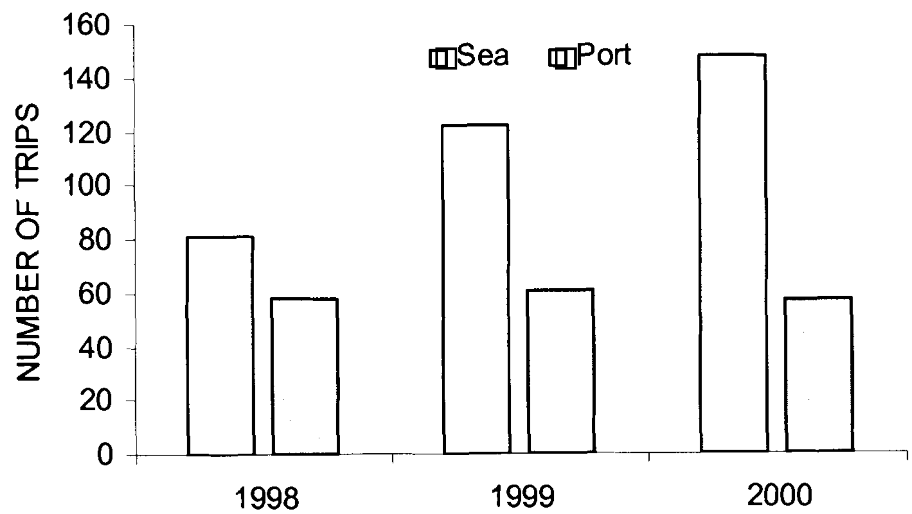
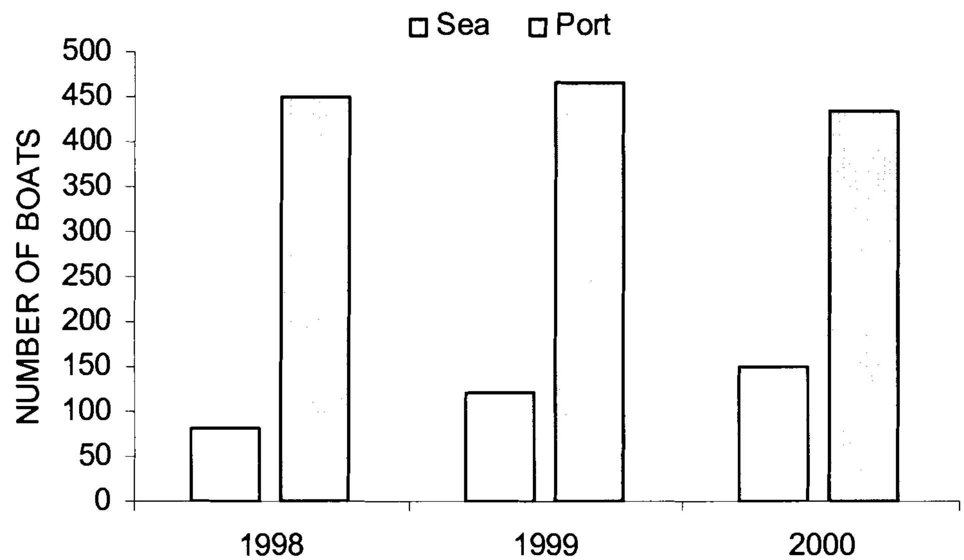


Figure 2.3. Comparison of yearly sampling effort between sea and port sampling in number of boats sampled.



Another regression analysis compared mean num/thsod and num/th for each county from sea and port sampling data. Sea sampling locations were categorized by lobster management area, whereas port sampling locations were categorized by county (Figure 2.1.). A table that lists each sea sampling location with the county that it is in was used to organize all locations according to county. Lincoln and Sagadahoc counties were combined because there were no sea sampling locations in Sagadahoc in 1998 and 2000. They are geographically adjacent and have smaller sample sizes on average than Cumberland or Knox counties (west and east of Lincoln and Sagadahoc, respectively; Figure 2.1.). The mean sample trip CPUE per county was calculated for 1998 to 2000. The regression analysis compared the two sampling programs by county for each year.

Size composition of the lobster catch between the sea and port sampling programs was compared using a non-parametric test, the Kolmogorov-Smirnov (KS) method (Zar, 1984). The test compares two independently sampled distributions to determine if the samples have been drawn from the same population. The size categories followed the 14% carapace length (molt) groupings used since 1989: 83-94mm, 95-108mm, 109-124mm, and 125-127mm (Thomas, 1973; Wilson et al., 2001). The frequency of each grouping was calculated for each month from May to November for 1998 to 2000 (Tables 2.3. through 2.5. and Figure 2.4.). The frequencies were then compared by the KS test.

Table 2.3. Frequency of 14% Grouping by Month for Sea and Port Sampling: 1998

Month	Program	83-94mm (%)	95-108mm (%)	109-124mm (%)	125-127mm (%)	Total # Lobsters
May	Sea	82.76	17.24	0.00	0.00	29
May	Port	83.10	14.79	2.11	0.00	142
June	Sea	81.88	15.94	2.17	0.00	138
June	Port	83.71	15.43	0.86	0.00	350
July	Sea	85.16	13.60	1.24	0.00	728
July	Port	83.09	16.36	0.55	0.00	550
August	Sea	87.41	11.37	1.22	0.00	1398
August	Port	87.67	12.09	0.23	0.00	860
September	Sea	86.91	11.92	1.10	0.07	1451
September	Port	86.94	12.61	0.45	0.00	1110
October	Sea	84.82	14.68	0.20	0.30	1008
October	Port	88.02	11.73	0.25	0.00	810
November	Sea	84.92	12.81	2.26	0.00	398
November	Port	93.20	6.80	0.00	0.00	250
Mean	Sea	84.84	13.94	1.17	0.05	735.71
Mean	Port	86.53	12.83	0.64	0.00	581.71

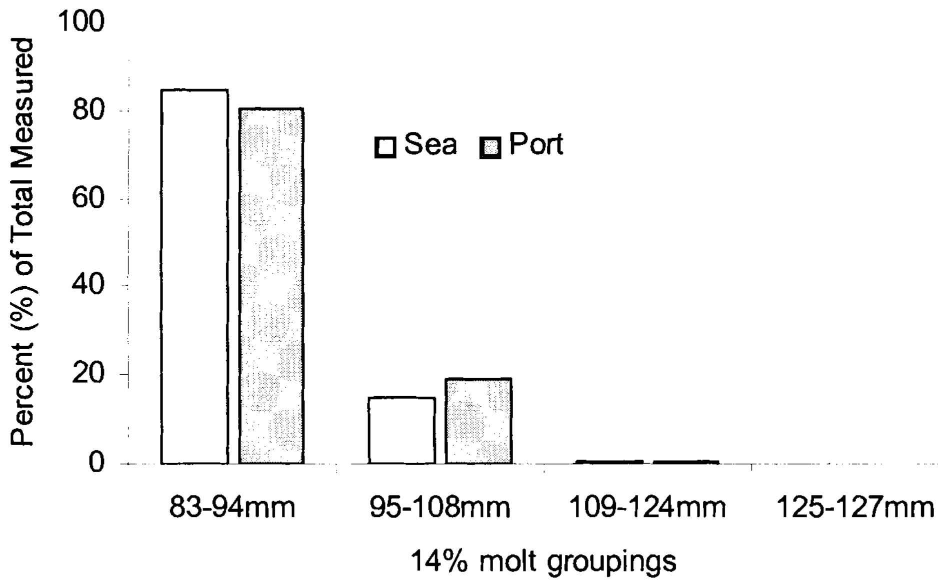
Table 2.4. Frequency of 14% Grouping by Month for Sea and Port Sampling: 1999

Month	Program	83-94mm (%)	95-108mm (%)	109-124mm (%)	125-127mm (%)	Total # Lobsters
May	Sea	83.68	14.58	1.74	0.00	631
May	Port	86.92	12.69	0.38	0.00	260
June	Sea	82.51	14.78	2.59	0.12	812
June	Port	84.47	13.40	2.13	0.00	470
July	Sea	86.99	12.40	0.60	0.00	1161
July	Port	85.64	13.66	0.69	0.00	1010
August	Sea	86.16	12.80	0.97	0.07	1438
August	Port	83.20	16.39	0.41	0.00	970
September	Sea	87.01	12.77	0.22	0.00	1801
September	Port	83.48	16.41	0.11	0.00	920
October	Sea	80.06	17.99	1.95	0.00	1284
October	Port	81.11	18.33	0.56	0.00	540
November	Sea	80.60	17.79	1.61	0.00	933
November	Port	92.58	7.42	0.00	0.00	310
Mean	Sea	83.86	14.73	1.38	0.03	1151.43
Mean	Port	85.34	14.05	0.61	0.00	640.00

Table 2.5. Frequency of 14% Grouping by Month for Sea and Port Sampling: 2000

Month	Program	83-94mm (%)	95-108mm (%)	109-124mm (%)	125-127mm (%)	Total # Lobsters
May	Sea	82.57	15.29	2.03	0.12	1629
May	Port	86.07	12.14	1.43	0.36	280
June	Sea	84.80	13.55	1.54	0.10	1948
June	Port	83.40	15.06	1.54	0.00	259
July	Sea	84.46	14.98	0.49	0.07	8527
July	Port	80.40	19.20	0.27	0.13	750
August	Sea	83.24	16.37	0.36	0.03	11186
August	Port	87.97	11.73	0.30	0.00	1006
September	Sea	78.78	20.37	0.84	0.01	7006
September	Port	81.94	17.58	0.48	0.00	620
October	Sea	80.00	18.73	1.23	0.03	6566
October	Port	76.79	22.26	0.94	0.00	530
November	Sea	74.16	20.83	4.73	0.28	7504
November	Port	91.25	8.33	0.42	0.00	480
Mean	Sea	81.14	17.16	1.60	0.09	6338.00
Mean	Port	83.97	15.19	0.77	0.07	560.71

Figure 2.4. Example size composition data from July 2000.



Results

Regression analysis of the two measures of catch (i.e., the standardized num/th and lbs/th) within the sea and port sampling data sets indicated that slopes were not significantly different from 1 (the obtained $p < 0.05$), intercepts not significantly different from 0 (the obtained $p > 0.05$) and all coefficients of determinant r^2 were greater than 0.90 (Tables 2.6. and 2.7.). Therefore, we concluded that there was no difference in using numbers or pounds to compare CPUE for both the sampling programs.

Table 2.6. Comparison of numbers and pounds as a measure of catch from the Port Sampling Program in 1998 - 2000. Mean CPUE per sampling trip: number/trap haul vs. pounds/trap haul.

Regression Statistic	1998	1999	2000
Slope	0.996	0.997	0.997
Slope p value	0.000	0.000	0.000
Intercept	0.000	0.000	0.000
Intercept p value	1.000	1.000	1.000
Adjusted r^2	0.99	0.99	0.99
N (Number of sampling trips)	58	61	61

Table 2.7. Comparison of numbers and pounds as a measure of catch from the Sea Sampling Program in 1998 - 2000. Mean CPUE per sampling trip: number/trap haul vs. pounds/trap haul.

Regression Statistic	1998	1999	2000
Slope	0.988	0.982	0.953
Slope p value	0.000	0.000	0.000
Intercept	0.000	0.000	0.000
Intercept p value	1.000	1.000	1.000
Adjusted r^2	0.98	0.96	0.91
N (Number of sampling trips)	81	122	149

The analysis of CPUE data from the two sampling programs, conducted on a monthly time scale, revealed a trend in all five measures of CPUE data. Results for the regression analysis of CPUE by month include slope, regression p-value, r^2 adjusted by sample size, and number of data pairs (months) for the regression analysis (Tables 2.8. - 2.12.). A trend of improved relationship from 1998-2000 was seen in all CPUE measures (increased adjusted r^2 and smaller model p-values).

Table 2.8. Port sampling vs. Sea sampling monthly CPUE comparison regression results (Number/Trap Haul): May to November 1998-2000.

Regression Statistic	1998	1999	2000
Slope	0.97	1.75	1.38
Model P Value	0.079	0.011	0.005
Adjusted r^2	0.39	0.71	0.78
N (Number of Months)	7	7	7

Table 2.9. Port sampling vs. Sea sampling monthly CPUE comparison regression results (Number/Trap Haul Set-over-day): May to November 1998-2000.

Regression Statistic	1998	1999	2000
Slope	0.51	1.11	1.23
Model P Value	0.144	0.010	0.001
Adjusted r^2	0.36	0.71	0.91
N (Number of Months)	7	7	7

Table 2.10. Port sampling vs. Sea sampling monthly CPUE comparison regression results (Number/Boat Hour): May to November 1998-2000.

Regression Statistic	1998	1999	2000
Slope	1.24	1.41	1.31
Model P Value	0.044	0.009	0.002
Adjusted r^2	0.51	0.73	0.85
N (Number of Months)	7	7	7

Table 2.11. Port sampling vs. Sea sampling monthly CPUE comparison regression results (Pounds/Trap Haul): May to November 1998-2000.

Regression Statistic	1998	1999	2000
Slope	0.90	1.77	1.37
Model P Value	0.150	0.013	0.003
Adjusted r^2	0.24	0.69	0.83
N (Number of Months)	7	7	7

Table 2.12. Port sampling vs. Sea sampling monthly CPUE comparison regression results (Pounds/Trap Haul Set-over-day): May to November 1998-2000.

Regression Statistic	1998	1999	2000
Slope	0.51	1.08	1.20
Model P Value	0.144	0.012	0.001
Adjusted r^2	0.25	0.70	0.89
N (Number of Months)	7	7	7

CPUE is used as a relative measure of fish stock abundance, so while the comparison of the CPUE values is important, time series plots of CPUE help give a more complete picture on differences in temporal variations of stock abundance implied by different measures of CPUE. Two measures of standardized CPUE (num/th and num/thsod) were plotted from port and sea sampling data on a monthly time scale for 1998-2000 (Figures 2.5. and 2.6.). The variation above or below the mean was consistent between the two sampling programs from 1998-2000. The degree and pattern of variation differed between the two measures of CPUE. Num/thsod showed greater variation from the mean than num/th. The two measures also depicted increases or decreases in CPUE differently. What appeared to be a dramatic change in num/thsod would not appear as dramatic in num/th, or an increase in num/th for one month would be a decrease in num/thsod in the same month (i.e. Port sampling, November 2000; Figures 2.5. and 2.6.).

Figure 2.5. Standardized Number per Trap Haul by month:1998-2000.

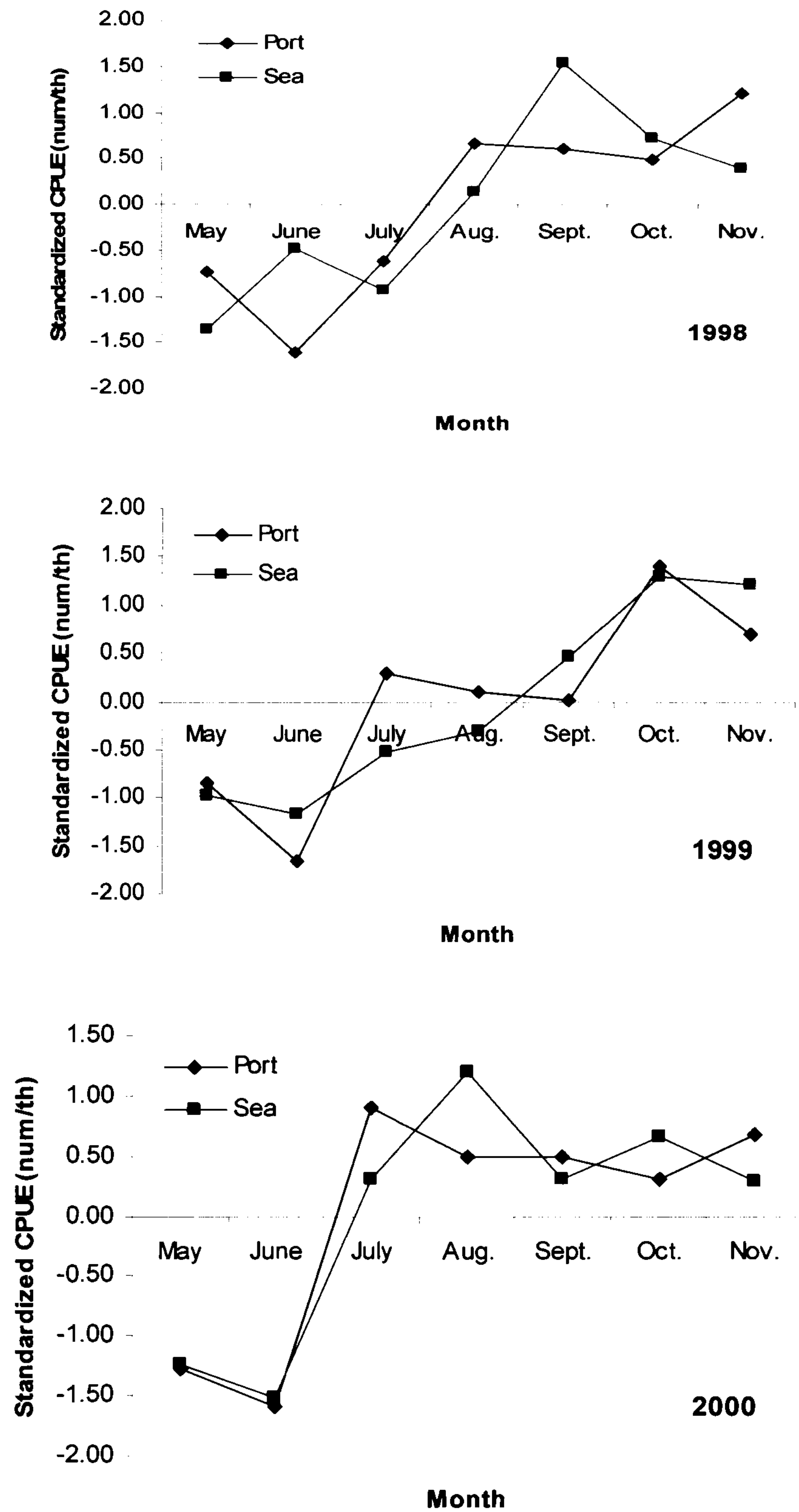
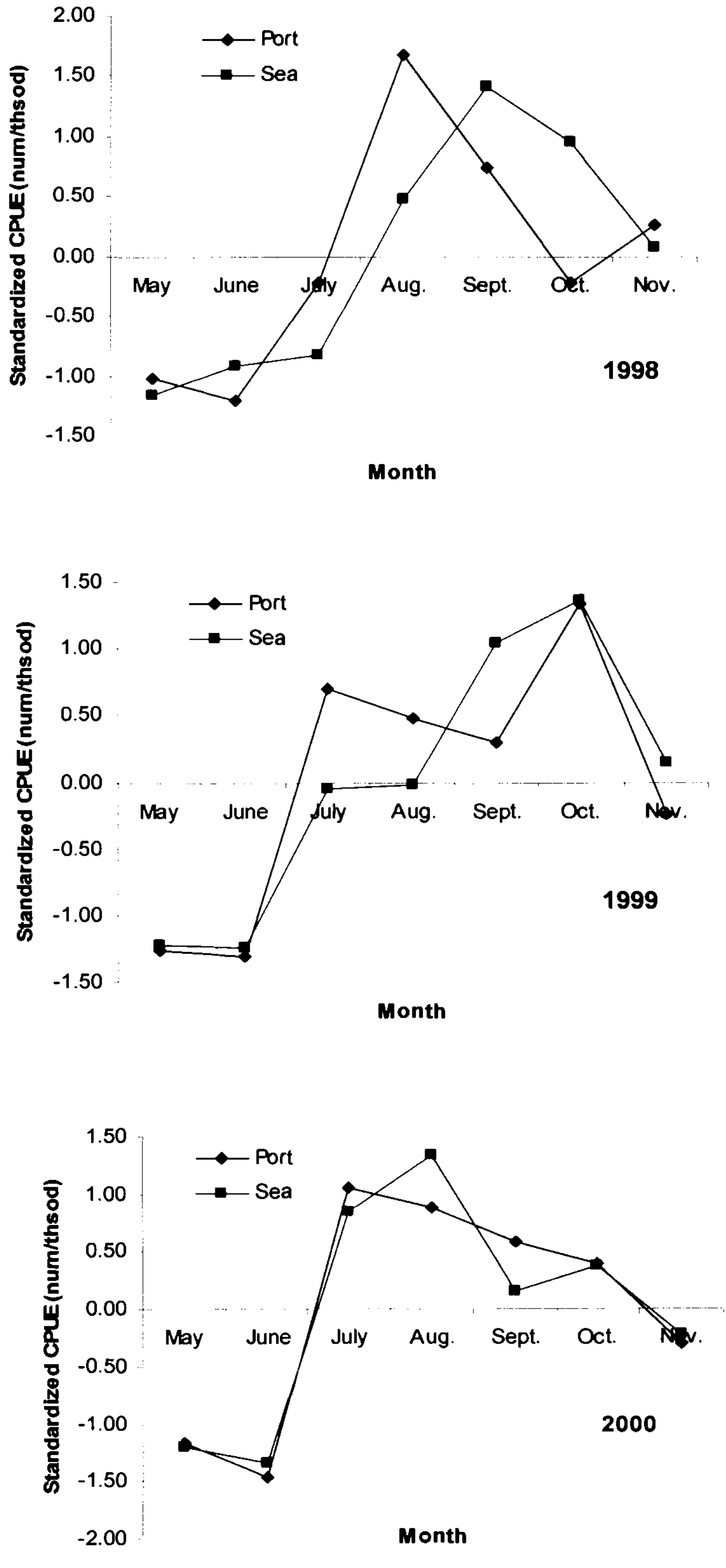


Figure 2.6. Standardized Number per Trap Haul Set-Over-Day by month:1998-2000.

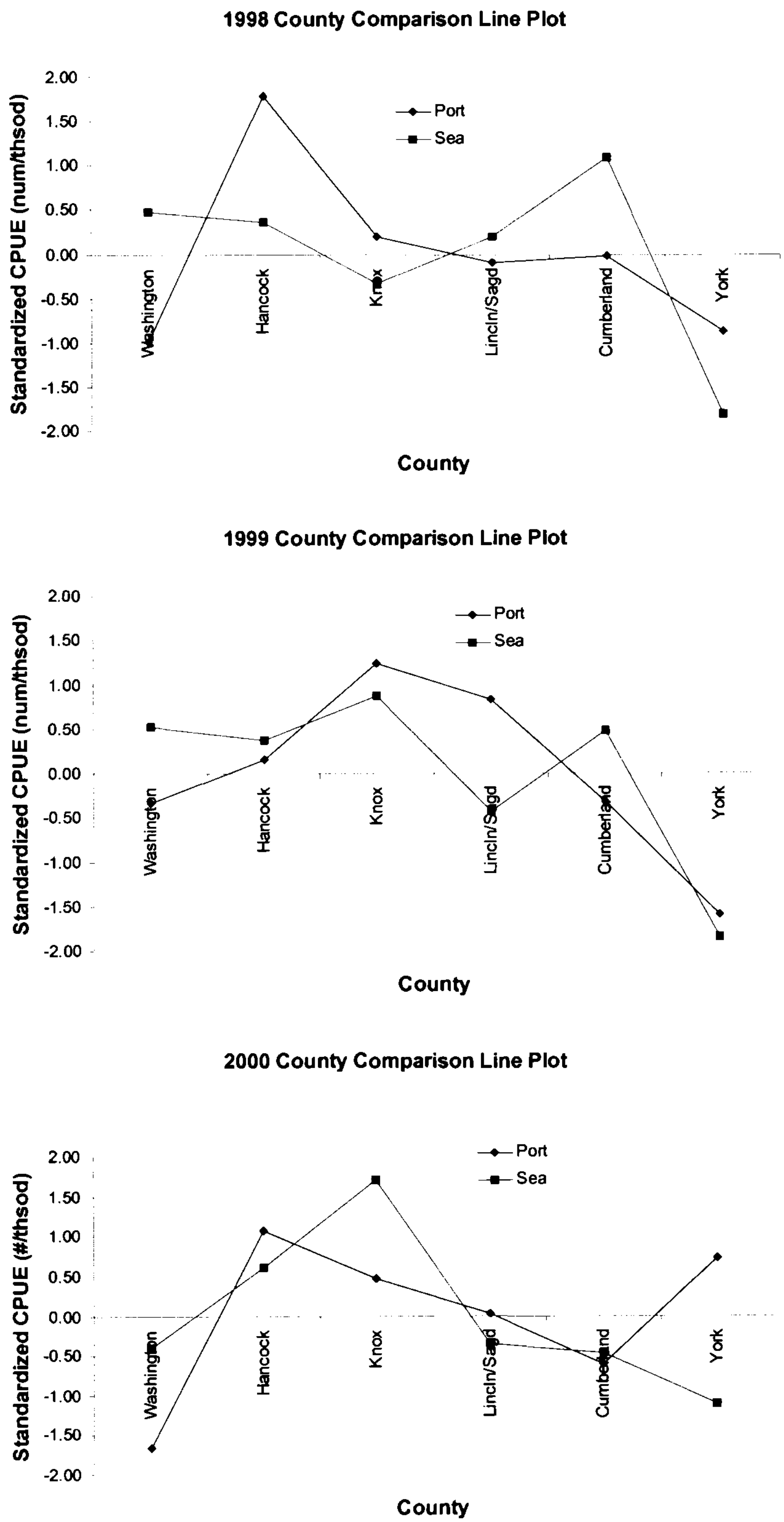


The coastal counties from Washington to York were compared to identify if the two sampling programs varied by geographic region. Two measures of CPUE (num/thsod and num/th) were used in the regression analysis. The relationship between the two programs was not significant in any of the three years ($P > 0.05$, Adj. $R^2 < 0.5$) (Table 2.13.). Standardized CPUE line plots show the degree of variation about the mean in the data from the two programs and further illustrate the spatial differences detected (Figure 2.7.).

Table 2.13. Port sampling vs. Sea sampling: Washington to York county CPUE comparison regression results (Number/Trap Haul Set-over-day): May to November 1998-2000.

Regression Statistic	1998	1999	2000
Slope	0.12	0.57	0.20
Model P Value	0.52	0.140	0.541
Adjusted r^2	-0.11	0.32	-0.12
N (Number of Counties)	6	6	6

Figure 2.7. Standardized Numbers per Trap Haul Set-Over-Day by county:1998-2000



Estimates of size composition from the two sampling programs rarely differed during the three year sampling period (Table 2.14.). Yet over the three years they did become less similar with the size composition differing in November 1999 as well as in August and November 2000.

Table 2.14. Difference in Size Composition between Sea and Port Sampling by month and year. Kolmogorov – Smirnov Test: No difference = TRUE; Difference = FALSE

Month	1998	1999	2000
May	TRUE	TRUE	TRUE
June	TRUE	TRUE	TRUE
July	TRUE	TRUE	TRUE
August	TRUE	TRUE	FALSE
September	TRUE	TRUE	TRUE
October	TRUE	TRUE	TRUE
November	TRUE	FALSE	FALSE
Percent True	100.00%	85.71%	71.43%

Discussion

The comparison of the sea and port sampling program data was conducted on an absolute scale and a relative scale. The absolute scale was concerned with statistical differences in the absolute CPUE values of the two sampling programs, while the relative scale examined patterns over time between the two data sets. The strength of the statistical relationships between the two sampling programs varied depending on the measure of CPUE, the year, and whether time or area was the classification variable. The overall pattern that emerged on both absolute and relative scales was a strong correlation between sea and port sampling data over time from 1998-2000.

Little difference mean and median values for each CPUE measure suggests that the data are normally distributed (Table 2.2). Sea sampling tends to report higher values for monthly and area CPUE (Table 2.2.). Also, variation (CV) was usually higher in sea sampling (Table 2.2.). This may be caused by the differences in the choice of fishermen sampled in the two programs. Sea sampling may select more successful fishermen, while port sampling selects from a broader range of fishermen. Port sampling also samples from a larger number of boats (Figure 2.3.), which may explain why there is less variation (CV) in CPUE estimates (Table 2.2.). Variance is often reduced when sample size is increased. Standardized monthly CPUE values from both programs exhibit similar trends above and below the mean (Figures 2.5. and 2.6.).

The CPUE data grouped by county do not show this similarity and appear to vary differently around the yearly mean (Figure 2.7.). This may be a consequence of differences from comparing annual vs. monthly data. Also, port sampling randomly selects dealers and may not sample in the same county more than once a month or not at all. Sea sampling makes trips three times a month in each of the seven zones. This may result in a difference in sample size depending on the county, contributing to variations in CPUE. The CPUE estimates for each county can vary widely from year to year in either sampling program.

Size composition of the legal catch recorded by each program was statistically the same for the majority of the months from May to November. The differences in 1999 and 2000 may have been caused by the large increase in number of measured lobsters in sea sampling, particularly in 2000. Also of interest is that in November 1998-2000, over 90% of the lobsters measured by port sampling were in the first 14% grouping (83-94 mm). In contrast, 84% or less of the measured catch in sea sampling was in the first 14% grouping. Again, sample size may be the cause of this difference as well as the technique by which port sampling selects lobsters to be measured.

Conclusion

Multiple fisheries sampling programs are common in collecting fishery-dependent data (Hilborn and Walters, 1992), and have the potential to increase confidence in our ability to sample a fishery. These programs are often established by different fisheries management agencies (e.g. for stocks distributed across different states) and in different time periods, resulting in dissimilar spatial and temporal coverage of the fishery. This raises an important question in using information collected from multiple sampling programs in describing the fishery. Because different sampling programs are often created for different purposes and have different designs and different spatial and temporal coverage, the information derived from them may be inconsistent in indicating the status of the fishery, which may have negative impacts on stock assessment and management. A comparative study should be done to compare the consistency of data collected in different sampling programs, identify the causes of any inconsistencies, and recommend potential changes within the sampling programs.

Chapter 3

A SPATIAL ANALYSIS OF MAINE AMERICAN LOBSTER FISHERY ELECTRONIC LOGBOOK DATA

Chapter Abstract

Information about changes in fishing effort in relation to fish distribution is critically important because it can help fisheries managers interpret the temporal and spatial changes in catch per unit of effort. The American lobster fishery exhibits strong seasonal variation in the distribution of traps in the Gulf of Maine. Quantification of such variations will increase our understanding of the dynamics of the fishery and catch-effort data collected, which in turn will improve stock assessment and management of this important resource. In this study, we developed and applied two spatial statistical models, a moving window model and the empirical distribution function (EDF) model, to explore and describe data from the lobster fishery in order to quantify the spatial and temporal dynamics of fishing effort.

This study suggests that fishing effort data were clustered rather than randomly distributed for the entire fishing season in the Stonington area. Intensity or clustering of traps was not constant over the area and intensity shifts were observed from month to month with the overall fishing area expanding and contracting again from May to December. Therefore, we can state the data are not random in space or in time, but rather trap locations are clustered. Plots of nearest trap locations from May to December indicated that the trap locations were also not random at the smaller time scale. May locations were more random, but June through December locations were clustered. The nearest location distances of 50%, 90%, and 100% of trap locations varied by month, but

a general trend of decreased distances (90% of trap locations were *x* meters or less from the nearest trap) from May to September was observed, followed by increased distances from October to December. These analyses allow us to draw conclusions about the general conditions and changes in the fishery over time. As a result, we may be able to understand and identify the possible causes for these changes and their management implications. More comprehensive spatially-specific data will enable further analysis will greatly improve our understanding of the spatial dynamics of the fishery, which subsequently should improve fishery managers' capacity to assess and regulate stocks.

Introduction

Project Rationale

Most populations of organisms will generally exhibit patterns of distribution in space and in time. More specifically, the organisms can be found in various densities at different places and different times. Describing temporal and spatial variability in the abundance of large, mobile species is extremely difficult in part because abundance patterns often change and detection of this change depends on the scale at which populations are sampled. Fishermen are particularly good at learning and following what they perceive to be the local (small-scale) patterns displayed by their target organism. When fishermen follow the movements of a stock closely in a pursuit fishery, the distribution of effort in time and space often mirrors local stock abundance (Pelletier and Magal, 1996). Major shifts in fishing effort may indicate to a manager that a certain segment of the stock is moving to other areas, that catches have declined sufficiently to warrant searching elsewhere, or that fishermen are moving in response to increasing pressure from other fishermen. Information about changes in patterns of fishing effort in relation to the distribution of fish is critically important for fisheries managers because it can help interpret the temporal and spatial changes in catch rate often measured as catch per unit of effort (Hilborn and Walters, 1992).

One key issue involves selecting the correct spatial scale(s) to quantify change at short to long time scales. Patterns identified at small spatial scales cannot necessarily be extrapolated to a larger spatial scale if local patterns are not reflective of regional processes. Furthermore, the fishing patterns displayed by an individual fisherman will not necessarily be the fishing patterns of all other fishermen. The same can be said for changes on short time scales (i.e., day-to-day patterns are difficult to generalize for a month or a year).

Change can be understood intuitively; however, methods must be developed to quantify these changes (Hilborn and Walters, 1992). The objective of this study is to develop a new methodology for quantifying spatial and temporal patterns observed in a pursuit fishery. This methodology needs to account for variation among individuals while also detecting large-scale patterns. In addition, this methodology is necessary to understand the interactions between the characteristics of a fish stock and the fishery.

Density Dependence

Density-dependent mechanisms that influence fish population dynamics have been documented in a wide diversity of systems. The spatial area a stock occupies, A, and its abundance within that area, N, define its density, N/A. Many key fishery parameters (i.e., growth, survivorship, fecundity, species range) are influenced by this density. As the density changes, the parameters change as well, but not necessarily by the same order of magnitude. Density dependence in this study is considered a spatial concept because we are assessing changes within a unit of space at a single point in time (Paloheimo and Dickie, 1964).

Winters and Wheeler (1985) and Paloheimo and Dickie (1964) found that in an exploited fish stock, the area occupied by the stock decreases as abundance decreases. Therefore, density within fished areas remains relatively constant as more and more fish are removed from a population. The catchability coefficient, q, is often assumed to be constant in stock assessment (Hilborn and Walters 1992), but Paloheimo and Dickie (1964) found that it varied inversely with stock density. This finding suggests that the relationship between effective fishing effort (which is proportional to fishing mortality) and observed fishing effort changes when stock density changes.

Many stock assessment models assume that stock area is constant and independent of population abundance. In this assumption, the stock counteracts depletions in abundance with changes in density in a constant geographic area. Winters and Wheeler (1985) found that reductions in abundance of Atlantic herring were accompanied by proportional reductions in its range. A reduction, though not proportional, in school size was observed as well. They also found that the interaction between stock abundance and area would be nonlinear because stock movements would occur at different rates due to areas of less favorable habitat.

Fishing Effort and Stock Density

Intuitively, fishing effort will follow maximum stock density until the return, often measured by CPUE, drops below a certain threshold (i.e., a certain CPUE), and then effort will be put into searching for areas of higher stock density or CPUE. Thus, the feedback mechanism is essentially catch-per-unit effort (CPUE). In other words, a fisherman generally will keep fishing in an area as long as it is profitable to do so. However, this notion is somewhat over-simplified, as feedback that motivates a fisherman to change his activity may come from many different sources, ranging from the movements of other fishermen to water temperature to the price of fuel.

The dynamics of this situation depend on the gear type and the target species. Fishermen using fixed gear versus mobile gear will have different response times to changes in CPUE. Invertebrate stocks generally do not exhibit strong density dependence and therefore are not as quick to maintain density as pelagic stocks. The feedback to invertebrate fishermen may not be as rapid as feedback to pelagic fishermen when feedback is thought of in terms of CPUE. Schools of pelagic fish are able to traverse much greater areas than invertebrates such as lobster, and as a result, the time scale of density shifts will be much different. This will also result in a different time scale for shifts in effort.

This brings us back to the importance of selecting the correct temporal and spatial scales in studying changes in fishing effort and the exploited stock components. With an understanding of spatial and temporal changes in a fishery, it may be possible to understand, model, and at times, predict the underlying changes in the stock. Spatial analysis tools and theory now available can help to quantify the dynamics of a properly understood fishery.

Use of Spatial Analysis to Study Fisheries

The field of spatial analysis has found more applications since geostatistical methods were first developed for soil science and geology in the early 1900's (Hilborn and Walters, 1992; Webster and Oliver, 2001). The fields of environmental science, economics, and ecology are among many in which spatial data have been increasingly useful (Bailey and Gatrell, 1995). There has also been increasing interest in applying methods of spatial analysis to fisheries data.

Stratified random sampling is the traditional approach in determining spatial and temporal trends in variables such as species abundance or distribution, but different methods have become available through increased computational capacity. Warren (1998) compared stratified sampling with kriging in determining abundance and density of scallops from survey data and found that they yielded similar results. Mahon and Smith (1989) used a type of cluster analysis of demersal fish assemblages to characterize data obtained from fisheries independent trawl surveys. Most of the fisheries spatial analysis literature focuses on geostatistical interpolation of abundance (Maynou, et al., 1998; Maravelias and Haralabous, 1995; Maravelias, et al., 1996; Pelletier and Parma, 1994; Petitgas, 1993: 1998: 2001; Rivoirard, et al., 2000).

Spatial Analysis of the American Lobster Fishery

In this study we apply specific statistical methods to explore and model data from the lobster fishery in order to quantify the spatial and temporal dynamics of fishing effort. These analyses may allow us to draw conclusions about the general conditions and changes in the fishery over time. As a result, we may be able to understand and identify the possible causes for these changes and their management implications.

Qualitative data and some quantitative data on the patterns of seasonal shifts in effort have been collected using interviews and direct observations. The location of lobster gear varies seasonally and spatially in distinctive patterns (Acheson, 1988; Kelly, 1993). For instance, during the summer months (June through August), the fishery is concentrated in shallower, mostly inshore water with traps set relatively close together. In the fall and early winter (September through November), the fishery moves into deeper water and fishing gear spreads out and is less congested. This spatial pattern continues into the winter and spring (December through May), with fewer fishermen and less gear per fishermen in the water (Acheson, 1988; Kelly, 1993).

We will try to quantify this pattern in space and time using methods of spatial analysis. As a general assumption for our approach, the presence of lobster traps and the lobster population itself must be tightly coupled (Pelletier and Magal, 1996). Thus we expect lobstermen to position their traps in areas where a lobster population exists that can sustain a certain CPUE or level of profitability. We expect lobstermen to move their traps in response to changes due to any number of factors including: movement and trapability of lobsters (Miller, 1997), encroachment by other lobstermen (Acheson, 1988), or other environmental and economic factors. We will focus on observed changes in the patterns of trap placement without quantifying if they are correlated with changes in the lobster population itself.

Derived from the above assumption we have to decide on the data type itself. The options presented here are: (a) to interpret the locations of lobster traps as point observations or (b) to view the lobster count per trap (CPUE) as a continuous random variable, which is highly correlated to the underlying density of a lobster population. In other words, should we view the data as individual, definable points in space, or as a surface or area that has a continuous value for each unit of area (such as number per meter squared).

For our first approach, we decided to go with option (a), the spatial point pattern for the following reasons. First, lobstermen do not randomly place their traps; therefore, CPUE or any other value is not an absolute indicator of lobster population size in the area. And second, spatial point patterns are more easily modeled statistically. A spatial point pattern is a collection of points located within a defined area. The points can be locations of naturally occurring events, sampling locations, or locations with values associated with them (Kaluzny, et al., 1998).

While designing the approach, we considered several different options and decided to explore first order effects (i.e., the broader spatial and temporal scale changes in the dataset) in a general way and model the second order effects (i.e., a measure of spatial dependence between points) with respect to spatial randomness. This approach will allow us to visualize trends in lobster trap locations, numbers of traps, and numbers of lobsters over space and in time. We also hope to produce quantitative results concerning trends in the intensity of fishing effort.

Modeling Spatial Point Patterns: First Order Effects

Exploring first order effects (or properties) can be done by a multitude of statistical approaches. One common theme, however, is that they are all based on the calculation of a spatial mean as a continuous variable over the desired study region. Models capturing the trend of spatial point patterns are, for example, moving window analysis or kernel estimations (Cressie, 1993). These models attempt to determine whether the process is stationary over time. A process is stationary if the intensity is constant and the second order intensity depends only on the direction and distance between pairs of points, not on their absolute locations (Kaluzny, et al., 1998). Second-order intensity is a measure of spatial dependence between points (Bailey and Gatrell, 1995; Gatrell, 1995; Kaluzny, et al., 1998). Here, we decided to implement a moving window (Windholz, 2001).

Parameters that need to be set for this model include: the cell size of the resulting grid map representing the continuous variable intensity $\lambda(s)$ (where s is the coordinate vector $\vec{s} = s(x, y)$ of a location (x,y)) and the area of the moving window.

The result of the moving window is a continuous representation of several variables per unit area—or intensity $\lambda(s)$. These variables include locations of observations, number of traps, and number of legal lobsters. at the area of because of the A relatively large amount of data were collected in the Penobscot Bay region which was the study area for the moving window model (Figure 3.1). The parameters of the model were set to capture meaningful variation within this area and to determine whether the properties of the data set were stationary. This may be difficult or the results unclear as a consequence of limited data and different fishing strategies employed by lobstermen. For instance, some lobstermen find an area that yields a high CPUE and will place as many traps as possible in the area. Others prefer to avoid this "carpet bombing" approach and space their traps more evenly to obtain a high CPUE over a wider area for a longer period of time, thus reducing the effort required to move large amounts of traps over longer distances (Hillman, 2003).

Modeling Spatial Point Patterns: Second Order Effects

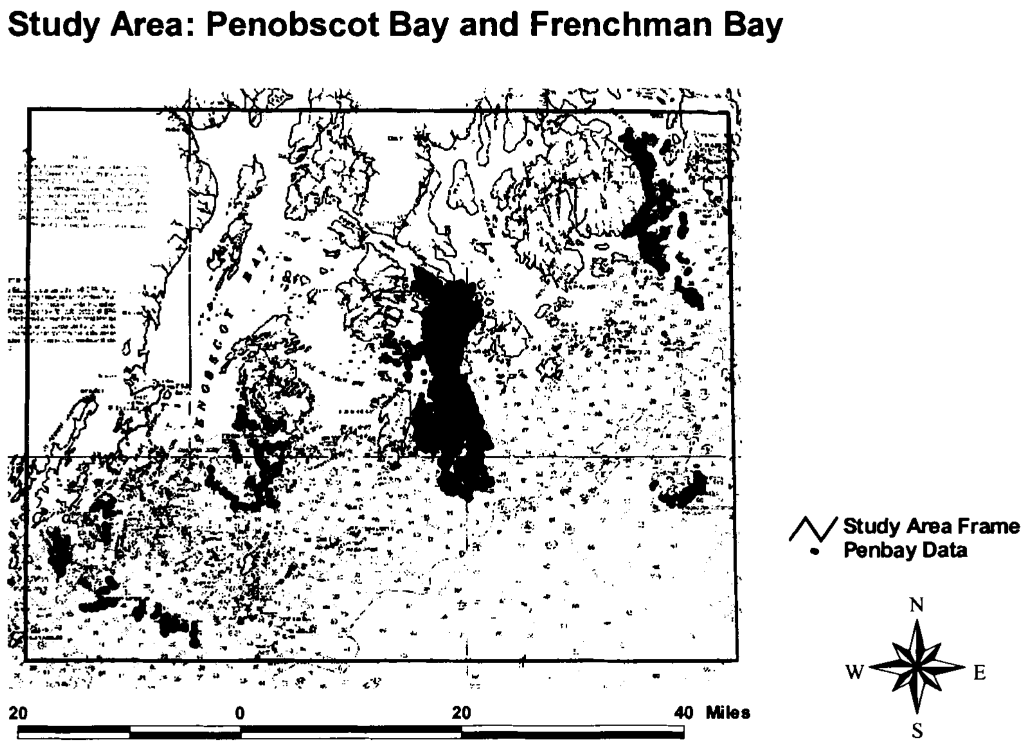
When modeling spatial point patterns we are interested in characterizing the dataset as clustered, random, or regular. The criteria for complete spatial randomness (CSR) are that the intensity of the spatial point pattern does not vary over the study area, and that there are no interactions among the points (Kaluzny, et al., 1998:150). Most statistical approaches aim at testing for CSR. Examples are the empirical distribution function (EDF) or the Clark-Evans statistic. The basic structures of these tests are based on the distance between observed point locations. The EDF measures these distances for the entire data set and is limited to nearest neighbor distances. Its basic calculation is $\hat{G}(y) = n^{-1} \sum_{d_i \leq y} 1$ where n is the number of locations in the study area, d_i is the distance from one point to the nearest point, and y is the specified nearest neighbor distance (Kaluzny, et al, 1998:152). *This equation will calculate the proportion of locations at a certain nearest neighbor distance.* A nearest neighbor distance (d_i) is simply the distance between one point in a spatial point process and the nearest point. By looking at these distances, we can make quantitative observations about the small-scale interactions between these points. This focus on a smaller scale than the moving window model constitutes a second order effect or property of the dataset. If the first order effects show the data set to be stationary, this model will also help to determine whether the data set is stationary and if the points are randomly located.

The application to the lobster fishery of these methods will be difficult first because of edge effects. By edge effects, we mean factors that constrain the placement of traps to certain areas in the space used by the fishermen. This space is limited because traps cannot be placed on land, on top of another fisherman's traps, across lobster zone boundaries, in water that is too deep or shallow, and in many other places. Second, because the data is fishery dependent, the occurrence of observations is not regular or evenly distributed over time or in space. The fishermen making the observations will do so disproportionately to each other and the data will be biased accordingly in each time increment to the fisherman making the most observations. This may create patterns that are due more to reporting than to attributes of the fishery. Third, the nature of the observations is such that individual traps cannot be pinpointed in space or in time. Observations may include one or two traps and may not be made at the specific location of the traps. Also, several observations may be made on the same trap in one period of time while other traps have not been observed at all in that time period.

Therefore we would expect that trap locations be non-stationary and non-random (or clustered). The usefulness of the empirical distribution function involves eliciting quantifiable trends over time in the interactions between trap locations and the values associated with those locations. These trends may inform and confirm qualitative observations that have long been accepted concerning the distribution and characteristics of effort in the lobster fishery. Furthermore, management practices based on assumptions about the fishery can be supported or questioned.

Figure 3.1. Study Area of Penobscot Bay and Frenchman Bay with Point Pattern

Displayed for Report Purposes Only – Not for public display



Methods and Materials

Data Preparation

Thistle Marine logbook data include logbook unit number, trip number, lobster market category id number, date and time, longitude, latitude, amount of lobsters caught, number of traps hauled on a string, and the ten minute square location of the traps. The data collected from May to December, 2000, were located in an MS Access table and queried to select the units (lobstermen) that recorded data in the Penobscot Bay region (Figure 3.1). The unit numbers were 1, 3, 6, 7, 16, 21, and 28. The majority of the data were collected by two lobstermen in the central part of the bay.

When a lobsterman records data from the trap or string of traps, he is prompted to enter the number of short, legal, oversize, egged, v-notched, and v-notched with eggs lobsters that were found in those traps. This results in a total of six records (for the six market categories) with the same latitude and longitude. To limit the records to one per each unique latitude and longitude, the records for legal size lobsters were queried from the dataset. This query resulted in a data set that included one record for each single point in space, with the number of legal lobsters caught near that point. We assumed that the data point was recorded approximately where the trap(s) were located.

ArcView Spatial Data Conversion

ESRI's ArcView 3.2a was used to visualize and manipulate the data. Thistle Marine logbook data is currently stored in MS Access table format which can be easily imported into Arcview. The data file (.mdb) was viewed as an event theme and converted to a shape file (.shp). Using the Arcview projection utility, the shape file (.shp) was converted from decimal degrees (lat/lon) to UTMs. The output projection was set as WGS 1984, UTM Zone 19.

In order to use the data in the moving window model and other spatial analysis tools, the UTM coordinates needed to be retrieved from the shape file. The MSDOS executable file *shp2sdo.exe* translates shape file coordinates into an oracle spatial data (.dat) file. This file is accessible through any database software. Alternatively, if available to the user, ArcGIS/INFO software should have a routine to make the UTM coordinates available in an output file. For step-by-step instructions, see Appendix A.

Moving Window Model

The spatial data file was saved as a text file for use in *lobstermeans.exe*, the MSDOS executable file containing the moving window model (Windholz, 2001). The inputs to the model include: (1) lower left corner coordinates of the study area (x,y in UTMs), (2) extent of the study area (x,y in meters), (3) resolution of the output file as the side of one pixel (in meters), and (4) the size of the moving window (half the side of the window in terms of pixels). Program instructions are in Appendix B., and the program code is in Appendix C.

The extent of the study area affects the degree of resolution obtainable by the model. The rectangular study area measured approximately 9,000 km^2 (100,000 m by 75,000 m), limiting the resolution to 10,000 m^2 (100 m by 100 m pixels). The model could not make the number of required calculations at finer resolutions without crashing or running for an hour or more. Lower resolutions were set at 62,500 m^2 (250 m by 250 m) and 250,000 m^2 (500 m by 500 m).

The inputs for the size of the moving window were generally set from 5 to 200, producing window sizes of 11 by 11 pixels to 401 by 401 pixels. One pixel is added to each side to ensure that there is always a center pixel (or an odd number of pixels). The window "moves" over the grid set by the resolution input, calculating a mean for the center pixel. Output files for mean number (*n*) of legal lobsters, traps, and record locations were produced in ascii format. Using Arcview 3.2a, the files were imported as Ascii/Raster data and saved as grid themes. The theme properties were adjusted to allow the data to be viewed because the means were on the order of $1x10^{-4}$ n/m^2 to $1x10^{-6}$ n/m^2. The data were classified using equal intervals with six digits to the right of the decimal. Blue to red dichromatic colors were selected to represent intensity from low (blue) to high (red). Import and display manipulation instructions are in Appendix D.

After viewing the results from the first set of model runs, the study area was divided into four vertical sections from west to east to separate four areas of influence (Rockland, Vinalhaven, Stonington, and Bar Harbor). The model was run for each area, and the resulting grid themes were adjusted to show intensity in the four areas.
Three lobstermen fishing in the Stonington area use Thistle Marine logbooks, so this area was selected for a finer temporal-scale analysis to protect confidentiality in other areas. The Stonington area data were filtered by month (May to December) and modeled to produce intensity plots of trap locations.

Complete Spatial Randomness (CSR) Modeling Using S-Plus

The Stonington area data set was selected for CSR modeling because of the intensity of recording. In order for the model results to be meaningful, the study area needed to be small with somewhat defined boundaries and relatively consistent reporting. The data set was queried by month from May to December. The empirical distribution function (EDF) Ghat (G^(y)) was calculated for each month.

Insightful Software's Splus Spatial Stats was employed for this analysis. The spatial module needs to be installed and enabled under the Splus file menu. The data from each month were saved in separate SDF data tables. Using the spatial randomness option in the spatial menu, monthly plots of Ghat were calculated. The data were extracted from the plots using the extract data option in the graph menu to obtain the exact nearest neighbor distances of 50%, 90%, and 100% of the record locations.

Results

First Order Effects – Moving Window Model

The intensity plots of Thistle Marine logbook record locations using the moving window model showed a large concentration of data points in the eastern half of the Penobscot Bay around Stonington (Figure 3.2.). A resolution of 250 m by 250 m pixels with a moving window of 21 by 21 pixels (averaging a 5,250 m by 5,250 m or 27.5 km^2 area) produced a relatively moderate scale intensity map of trap locations (Figure 3.2.). A resolution of 1000 m by 1000 m pixels with a moving window of 5 by 5 pixels (averaging a 5,000 m by 5,000 m or 25 km^2 area) produced a relatively coarse scale intensity map of trap locations (Figure 3.3.). Plots of mean number of legal lobsters or mean number of traps were not included in the results. The patterns of intensity were similar to mean locations, and there was a large amount of variability in how lobster counts were reported. Legal lobsters caught in a series of locations were sometimes reported at a single location. Traps per location varied from one to two, so lobsters per location reflected different levels of effort (one trap will catch fewer lobsters than two). Visual interpretation of the intensity maps did not allow more than general comparisons between the three measures of intensity (i.e., the intensity of lobsters was lower in this small area than the intensity of traps).

Figure 3.2. Trap Location Intensity May – December 2000; Entire Study Area Represented in 250 m x 250 m pixels

Penobscot Bay Trap Location
Intensity: Medium Resolution

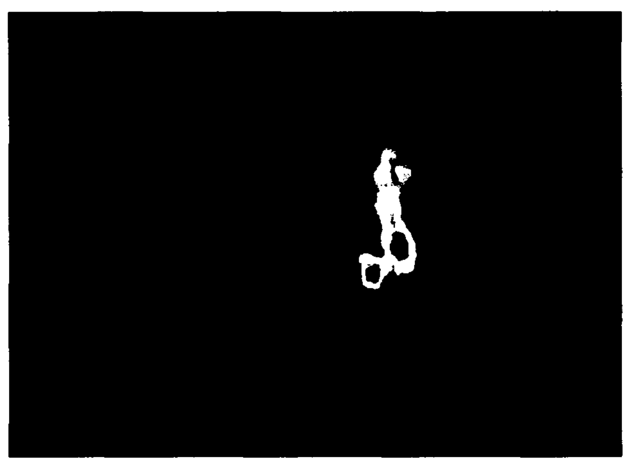
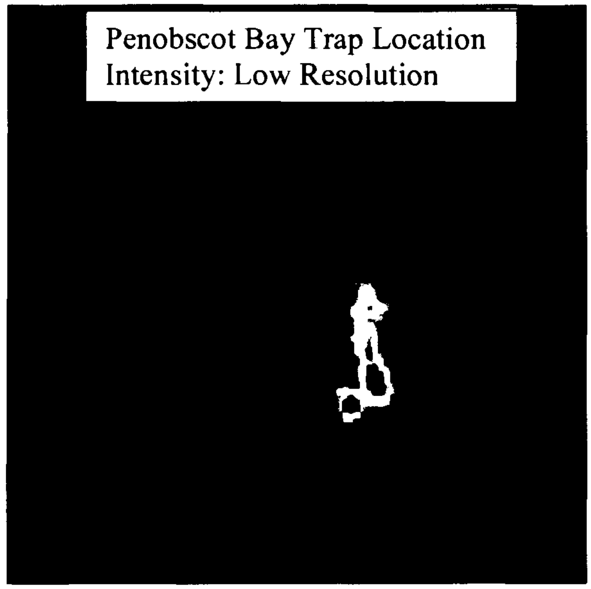


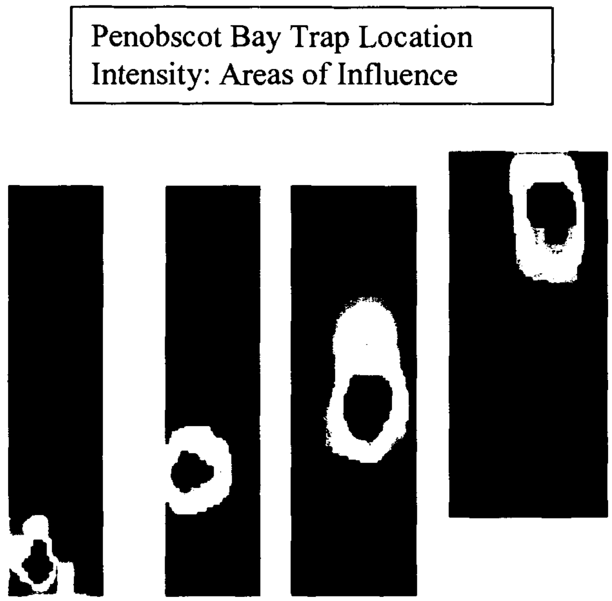
Figure 3.3. Trap Location Intensity May – December 2000; Entire Study Area

Represented in 1000 m x 1000 m pixels



It was necessary to separate the areas of influence into vertical sections to adequately view the intensity in those areas (Figure 3.4.). The approximate location of the greatest intensity or clustering of records (or traps) can be seen by the red areas. Intensity was not constant over the study area, suggesting that the data properties of trap location, number of traps, and number of lobsters are not stationary in space.

Figure 3.4. Trap Location Intensity for Tenants Harbor, Vinalhaven, Stonington, and Bar Harbor Areas of Influence Represented in 500 m x 500 m pixels; May – December 2000



Intensity plots of trap locations in the Stonington area on a monthly time scale produced similar results (Figures 3.5. through 3.12.). Intensity was not constant over the area and intensity shifts were observed from month to month with the overall fishing area expanding and contracting again from May to December. Intensity increased and then decreased during the same time period. Therefore, the data are not random in space or in time, but rather trap locations are clustered and have some level of interaction among them. This statement is based on the requirements for CSR: (1) intensity is invariate and (2) there are no point-to-point interactions.

Figure 3.5. Stonington Area Trap Location Intensity in 100 m x 100 m pixels; May 2000

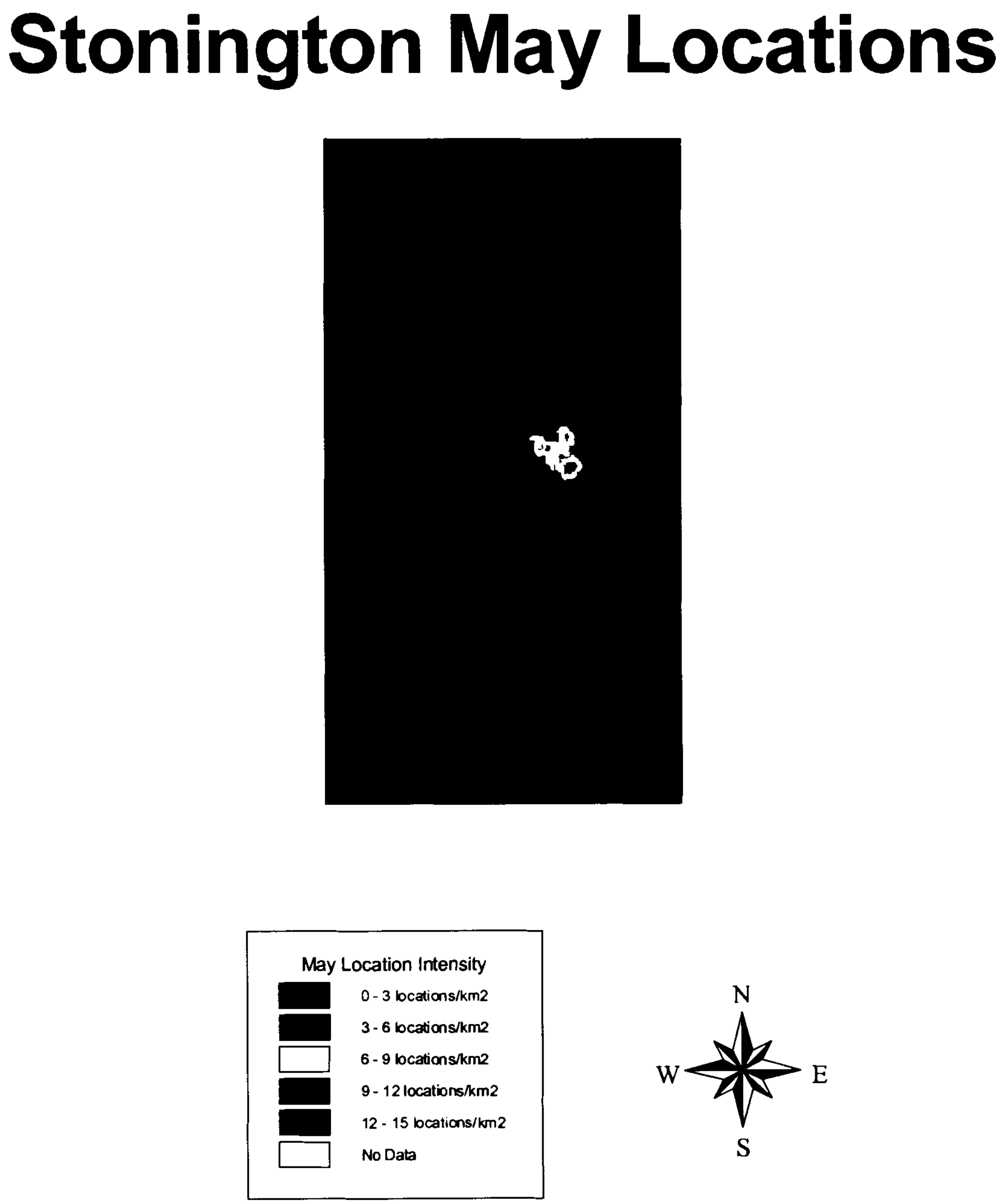


Figure 3.6. Stonington Area Trap Location Intensity in 100 m x 100 m pixels; June 2000

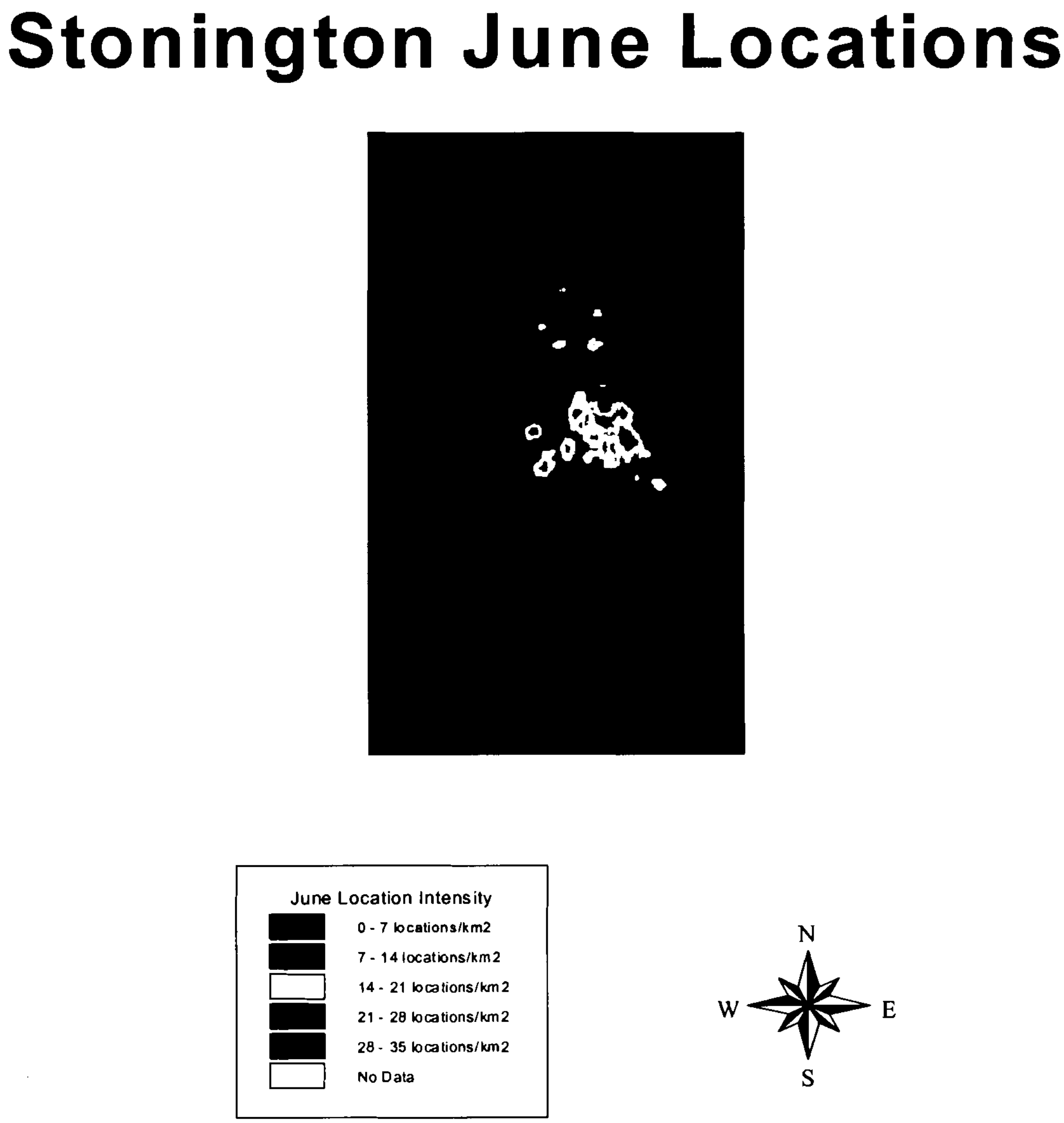


Figure 3.7. Stonington Area Trap Location Intensity in 100m x 100m pixels; July 2000

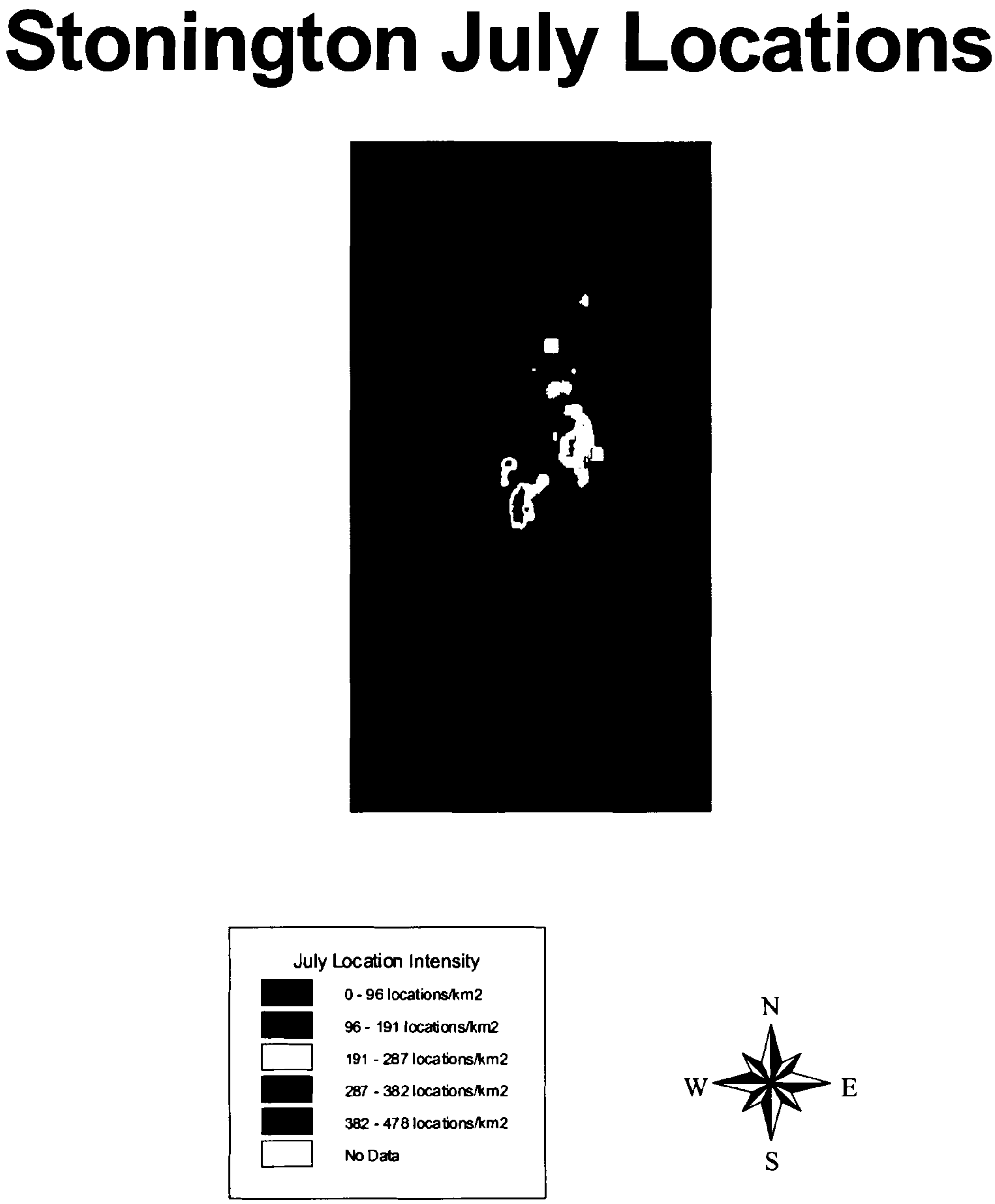


Figure 3.8. Stonington Area Trap Location Intensity in 100 m x 100 m pixels;

August 2000

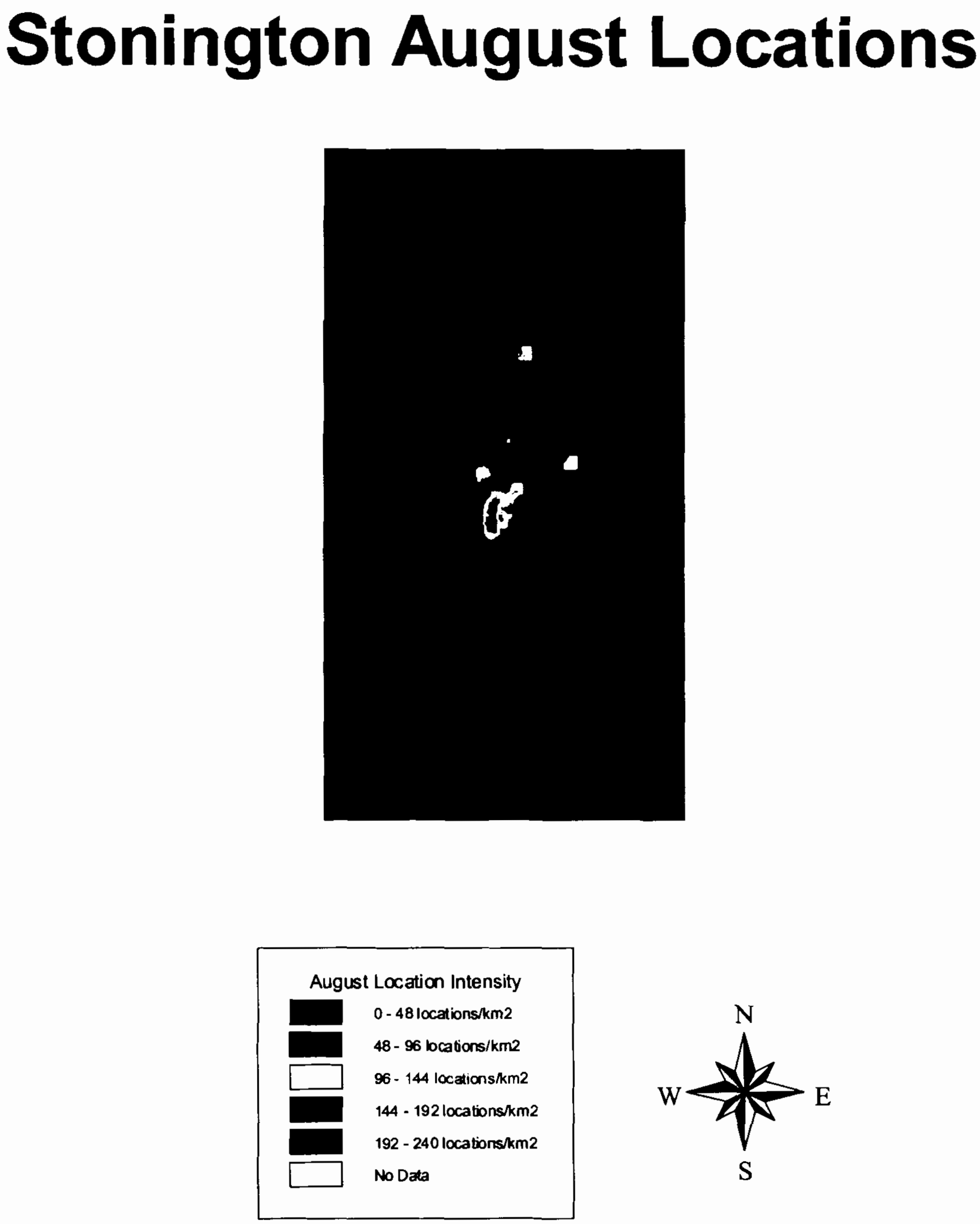


Figure 3.9. Stonington Area Trap Location Intensity in 100m x 100m pixels;

September 2000

Stonington September Locations

Figure 3.10. Stonington Area Trap Location Intensity in 100 m x 100 m pixels;

October 2000

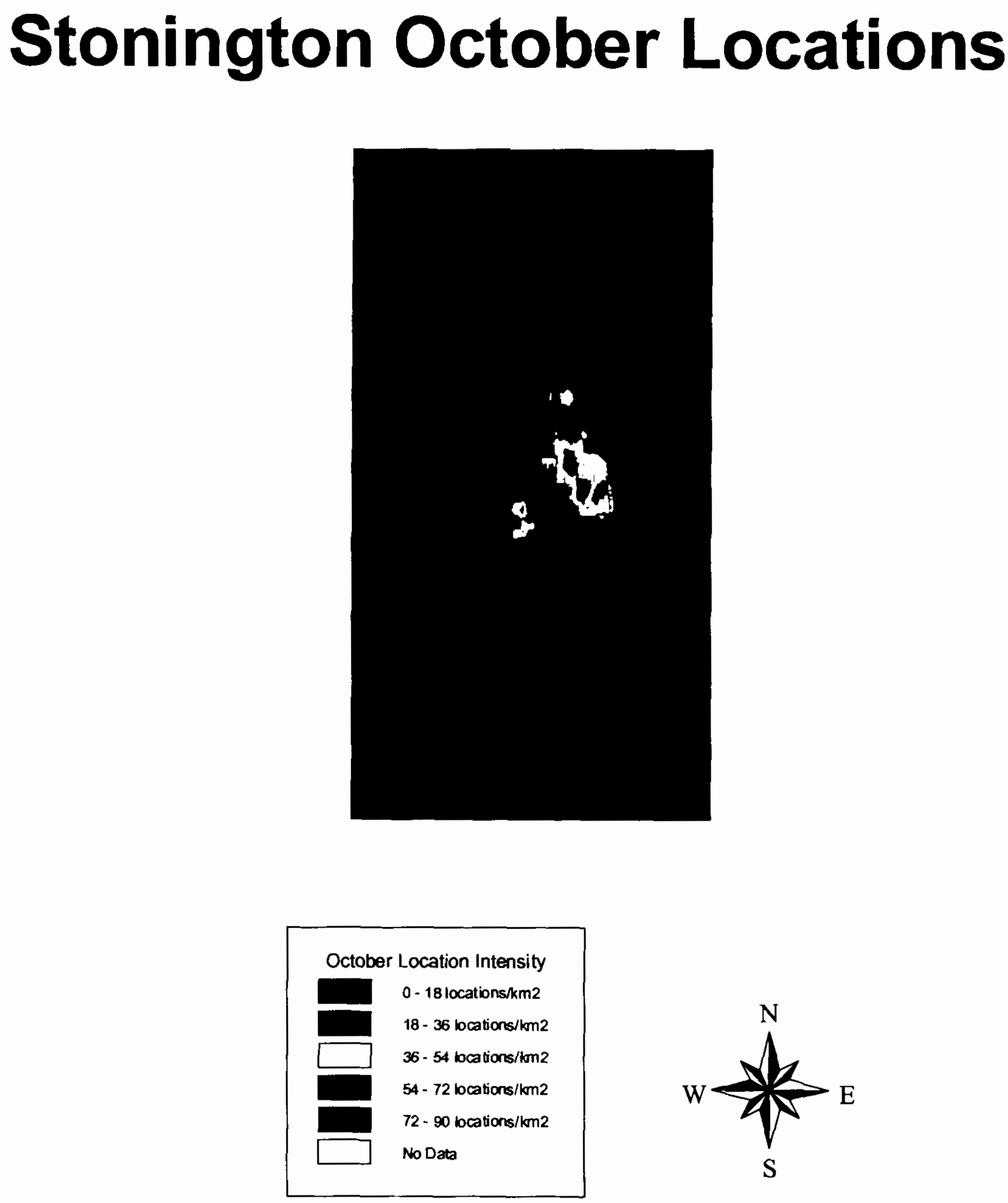


Figure 3.11. Stonington Area Trap Location Intensity in 100 m x 100 m pixels; November 2000

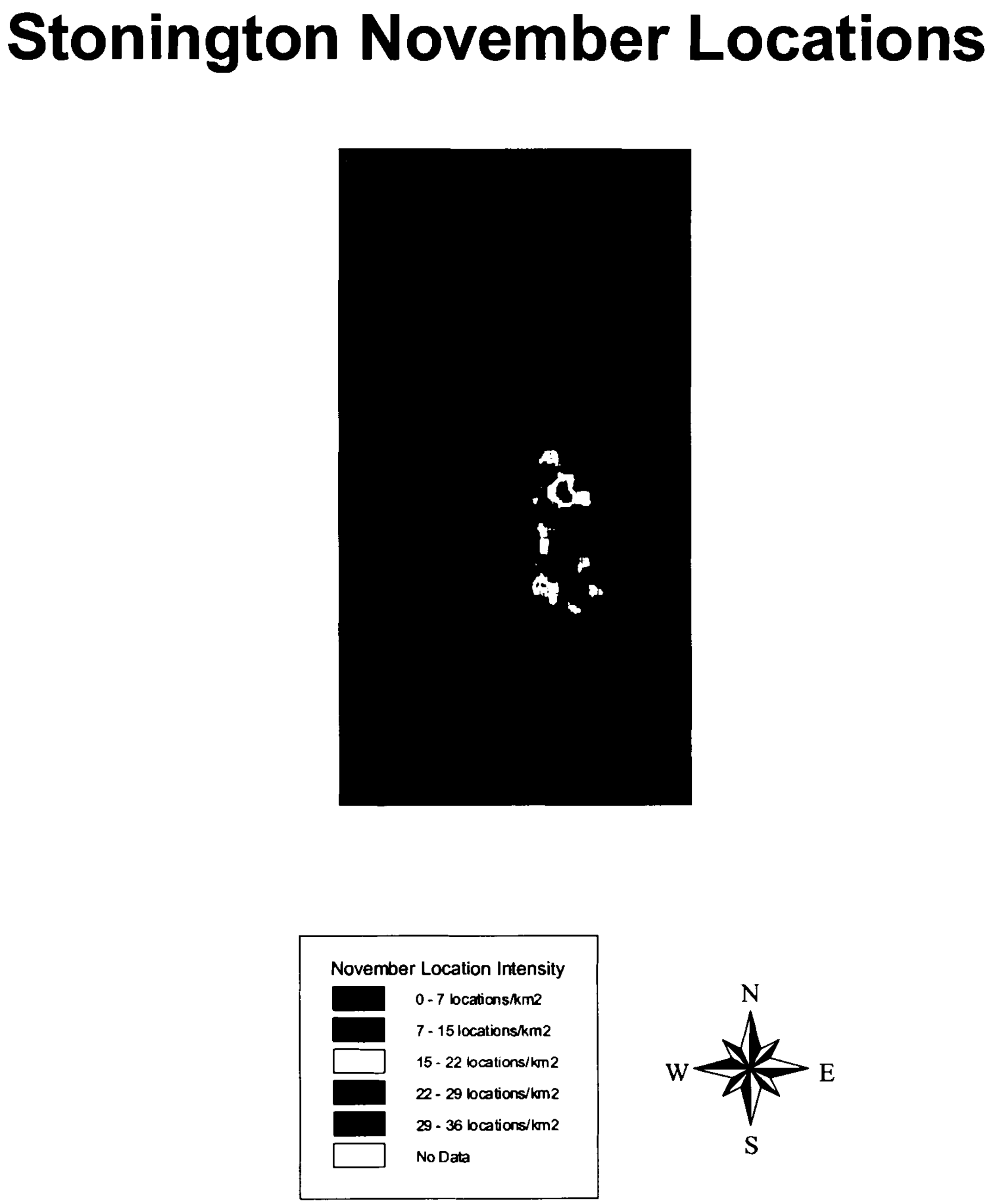
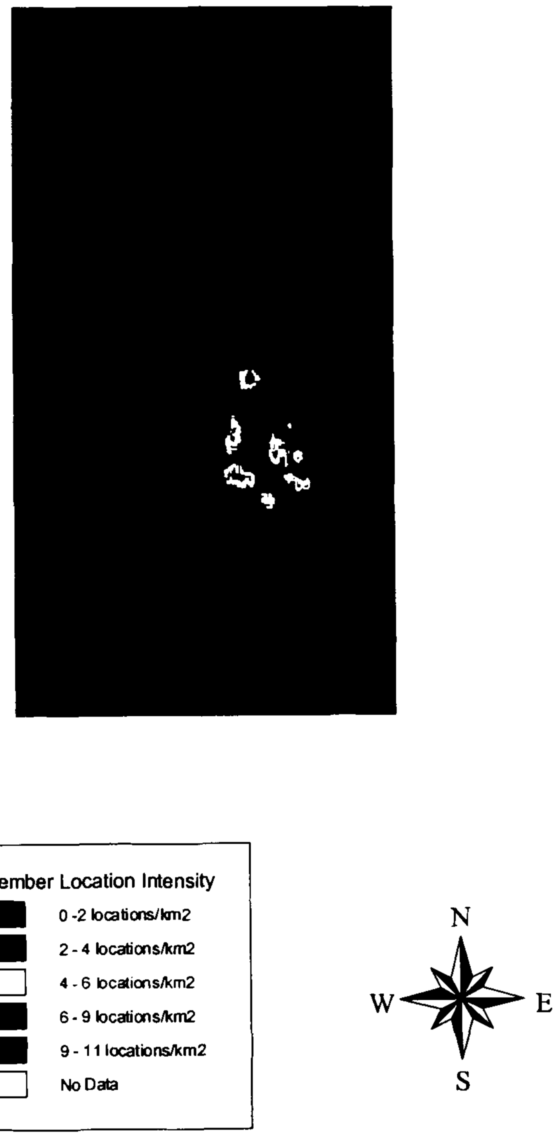


Figure 3.12. Stonington Area Trap Location Intensity in 100 m x 100 m pixels; December 2000

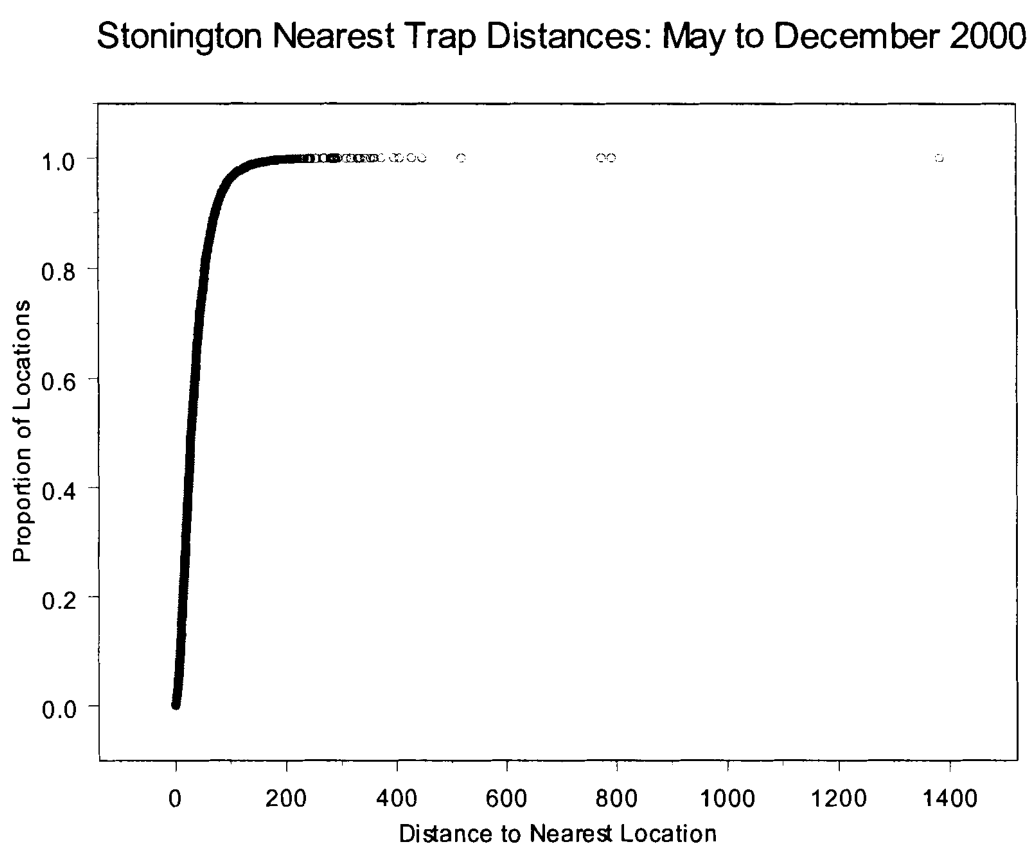
Stonington December Locations



Second Order Effects – Spatial Point Patterns

The use of the EDF (Ghat) model was aided by the intensity maps, and the focus of the study was narrowed on both spatial and temporal scales. An initial run of the model for the entire time period found that the data in the Stonington area was clustered and not randomly distributed (Figure 3.13). The excess of short distance locations in relation to the longest distance is an indicator of non-random distribution.

Figure 3.13. EDF Results for Stonington Logbook Record Locations from May to December 2000.



Plots of nearest trap locations from May to December indicated that the trap locations generally were also clustered at smaller time scales (Figures 3.14. through 3.21.). May locations were more random (Figure 3.14.), but June through December locations were clustered (Figures 3.15 through 3.21.).

Figure 3.14. EDF Results for Stonington Logbook Record Locations in May 2000.

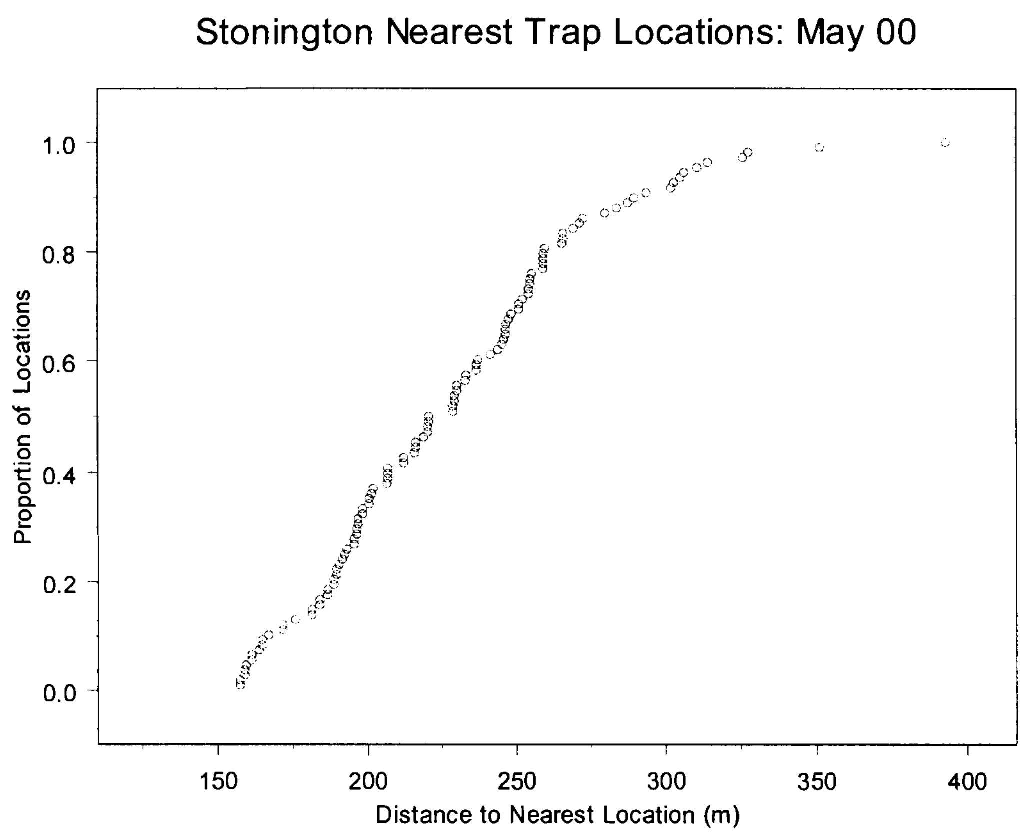


Figure 3.15. EDF Results for Stonington Logbook Record Locations in June 2000.

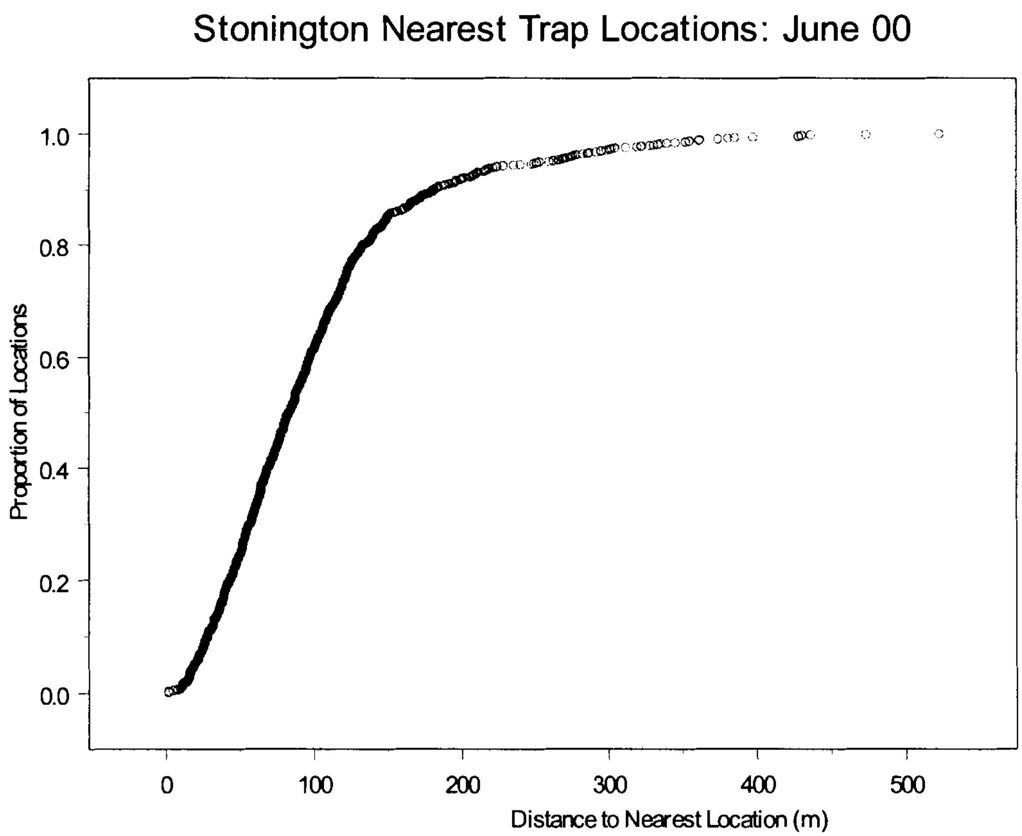


Figure 3.16. EDF Results for Stonington Logbook Record Locations in July 2000.

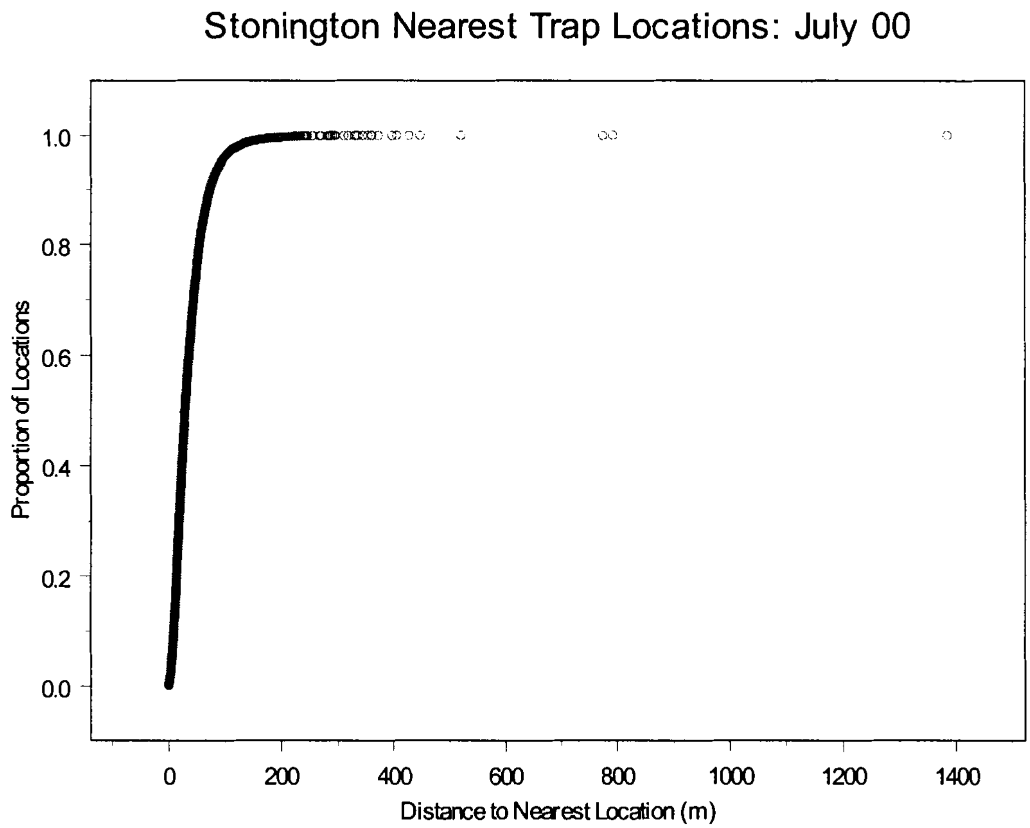


Figure 3.17. EDF Results for Stonington Logbook Record Locations in August 2000.

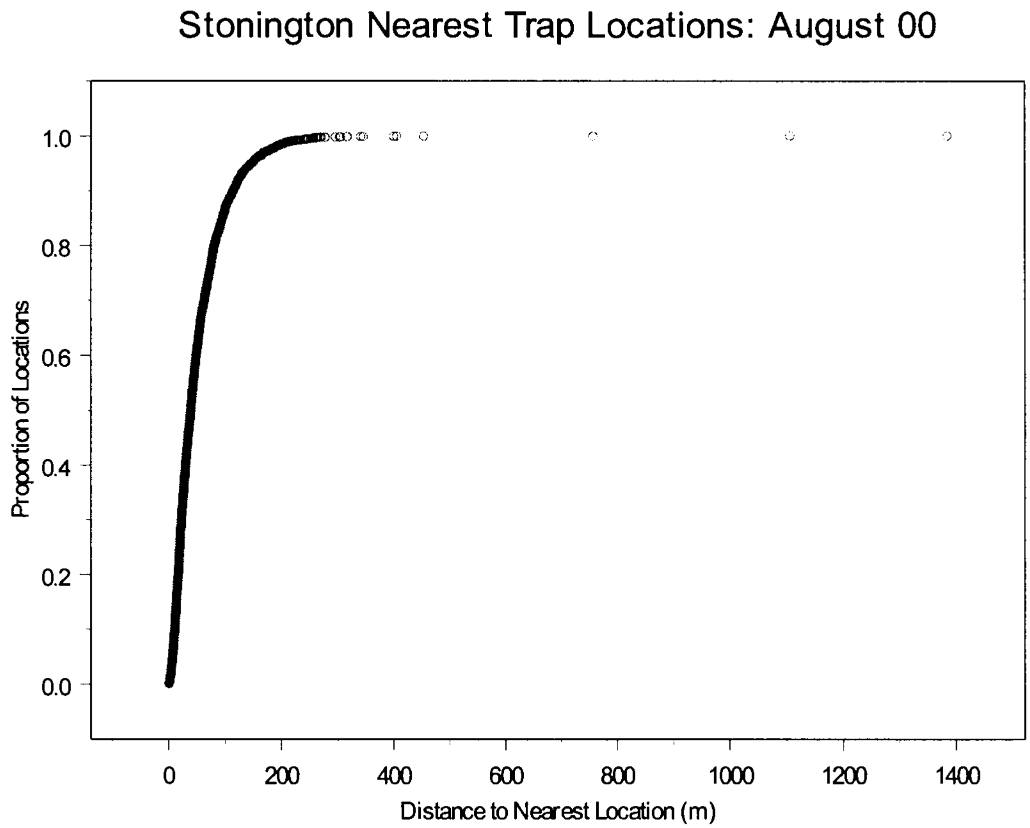


Figure 3.18. EDF Results for Stonington Logbook Record Locations in September 2000.

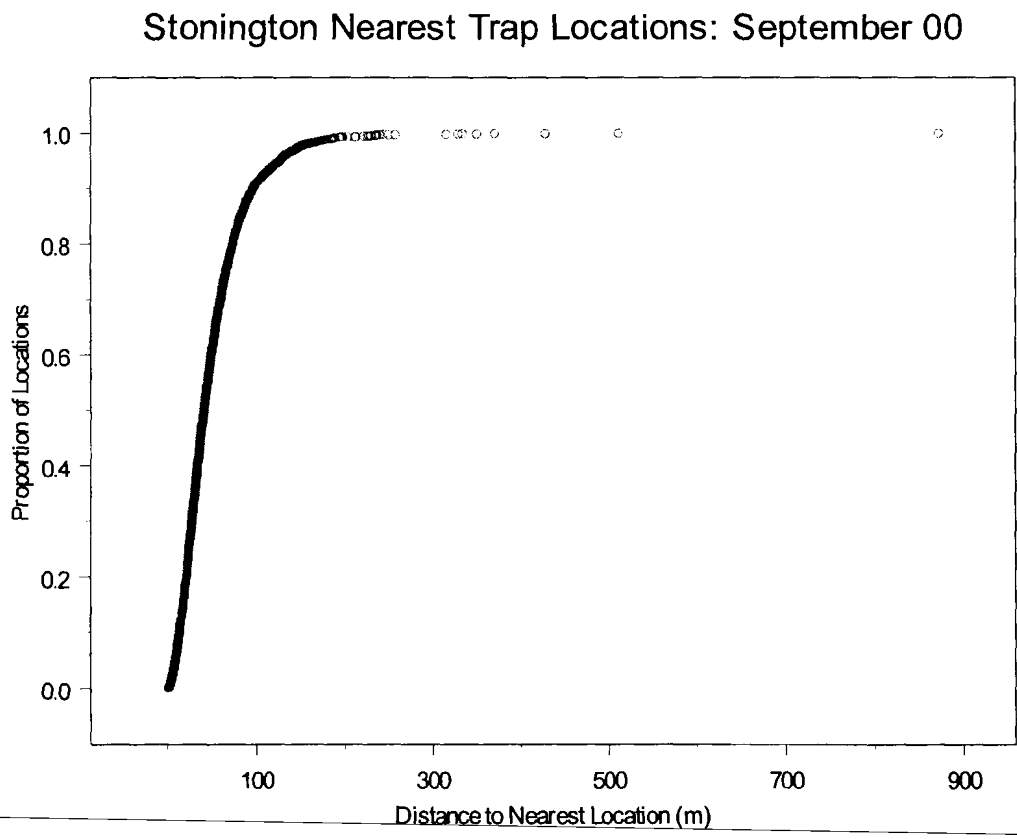


Figure 3.19. EDF Results for Stonington Logbook Record Locations in October 2000.

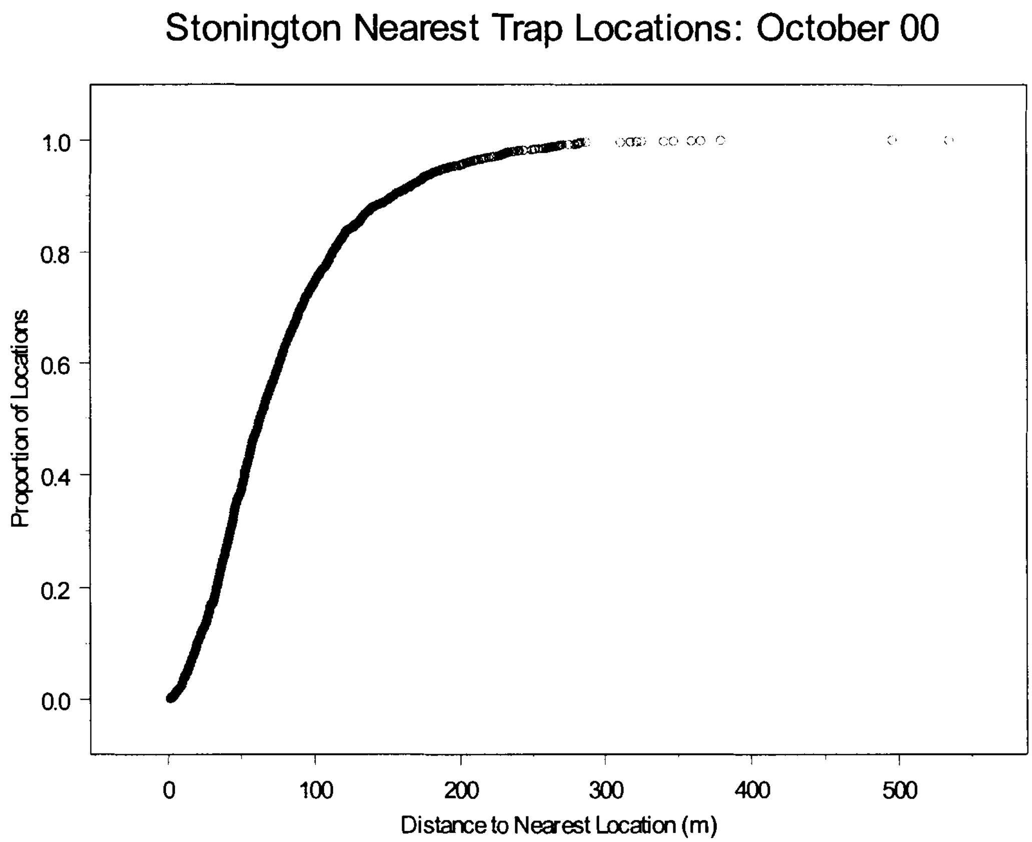


Figure 3.20. EDF Results for Stonington Logbook Record Locations in November 2000.

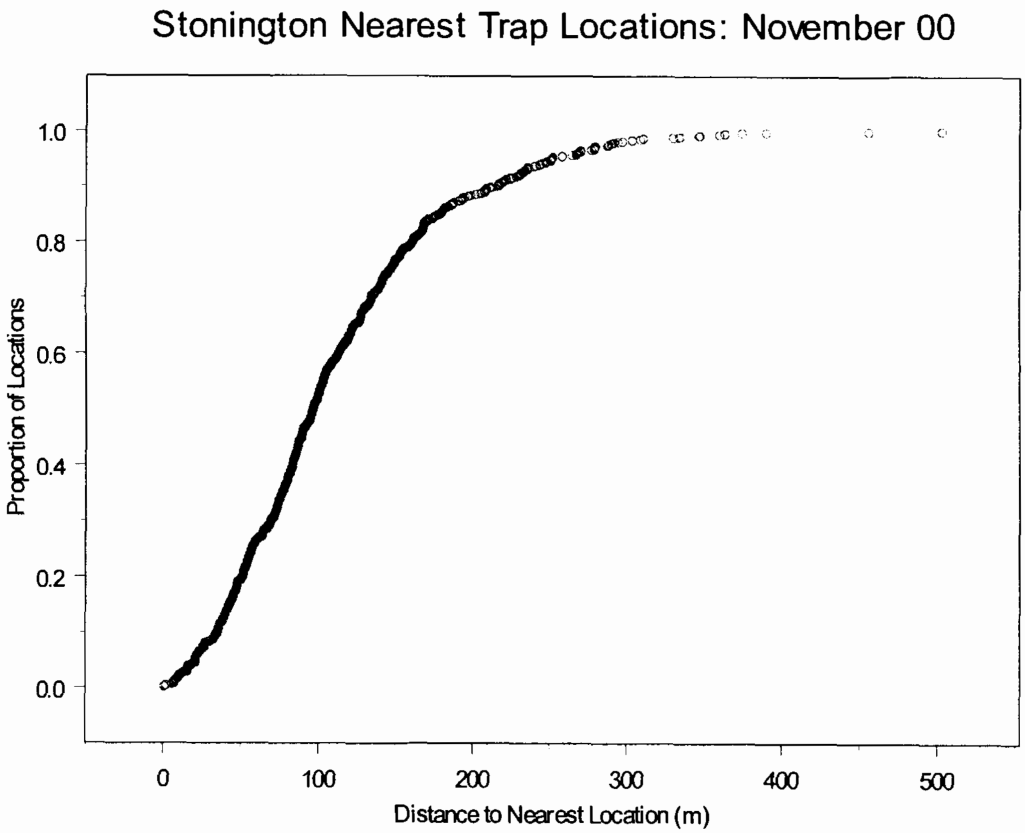
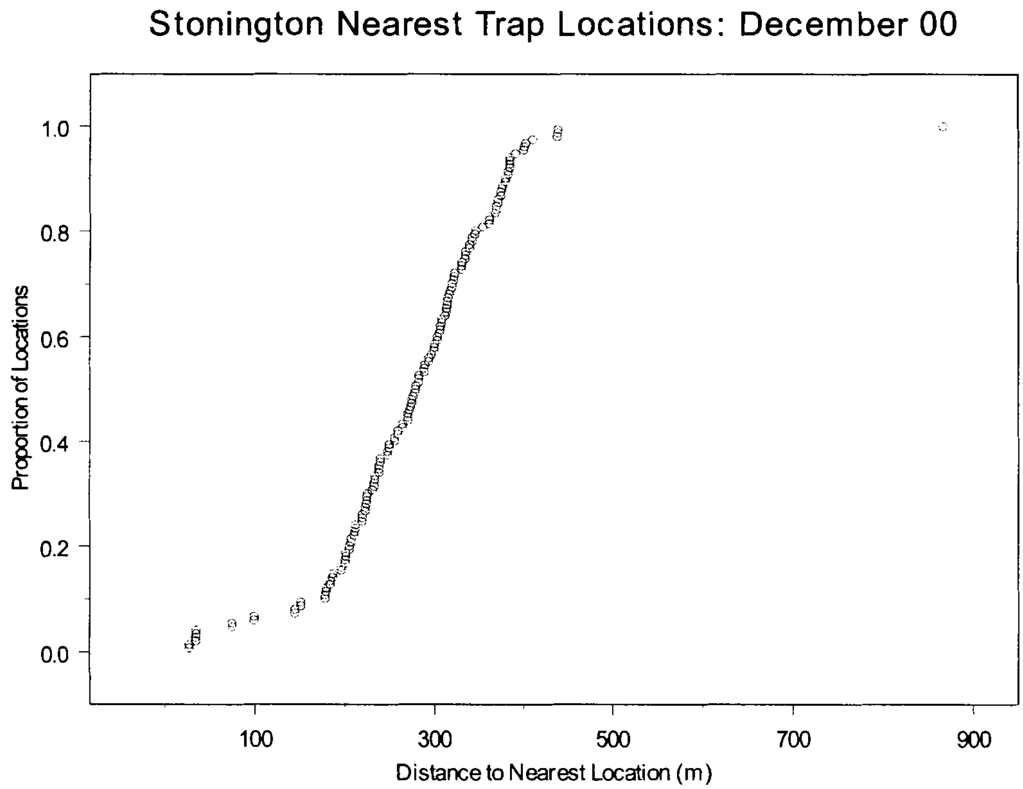


Figure 3.21. EDF Results for Stonington Logbook Record Locations in December 2000.

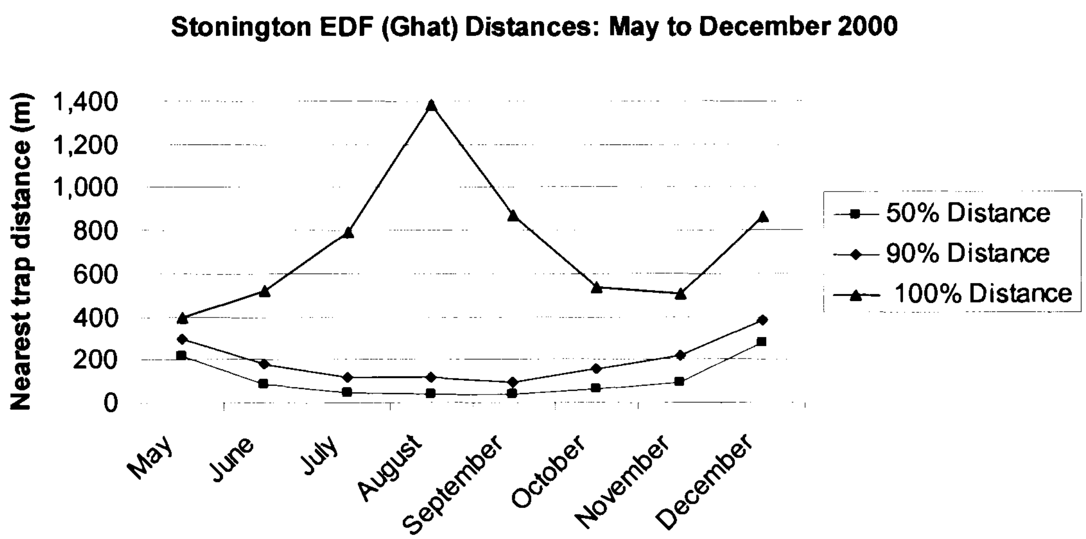


The nearest location distances of 50%, 90%, and 100% (ie. 50% of the logbook record locations were *x meters or less* from the nearest record location) of trap locations varied by month. In particular, a general trend of decreased distances from May to September was observed for the nearest location distances of 50% and 90%, followed by increased distances from October to December for these values (Table 3.1. and Figure 3.22.). The nearest trap distance for 100% of traps increased from May until August, and then decreased until November.

Table 3.1. Nearest Trap Distances by Proportion of Locations: May to December 2000.

Month	50% of Locations Distance (m)	90% of Locations Distance (m)	100% of Locations Distance (m)
May	220	293	393
June	82	182	523
July	50	117	793
August	39	115	1385
September	41	97	872
October	63	154	535
November	96	217	503
December	279	380	867

Figure 3.22. Nearest Trap Distances Measured by the EDF for 50%, 90% and 100% of Trap Locations by Month from May to December 2000.



Discussion

Thistle Marine logbook data do not currently depict adequately fishing effort of the Maine lobster fishery because of irregular reporting and relatively little participation by lobstermen. While the numbers of trap hauls that data have been collected on are far in excess of any current state monitoring program, the representation of the entire coast is not equal to either the lobster fishery sea or port sampling programs (Wilson et al., 2001). As this is the case, our analysis focused on lobstermen in one area of the coast who reported data somewhat regularly. This study provides an example for a methodology that could be employed if Thistle Marine logbook data better characterized the fishery. The results of the analysis characterized the data from the Penobscot Bay area to be (1) globally and locally non-stationary and (2) non-isotropic (i.e., the trap locations are not independent of other trap locations or of the space in which they are placed). This verifies previous qualitative assessments of the lobster fishery and trap placement decisions (Acheson, 1988).

The results of the initial moving window model runs illustrate how the representation of intensity is influenced by resolution and unequal sampling (Figures 3.2. through 3.4.). Low resolution can mask changes in small-scale intensity, while high resolution will provide too much detail to see the overall pattern. Unequal sampling masked data that existed in other parts of the Penobscot Bay area because the number of points underlying the grid in the Stonington area was disproportionate (Table 3.2.). Selecting the individual areas where enough data existed permitted observation of intensity patterns, which in turn directed us to select the specific area of Stonington. The reasoning behind refining the temporal and spatial scale was to determine if the large-scale pattern would be maintained on a smaller spatial scale.

Table 3.2. Thistle Marine Logbook Recording by Harbor Units.

Harbor	Number of Records	Months Recorded
Stonington A	12125	May - December 00
Stonington B	4487	June - October 00
Bar Harbor 1	1439	July, August, and October 00
Stonington C	3255	July - October 00
Vinalhaven 1	1119	October - November 00
Port Clyde 1	718	January 01 - February 01
Tenants Harbor 1	244	December 00 and February 01

Even though both series of runs showed the intensity of the means to be variable (and thus non-stationary), the data were tested for CSR because we were developing a methodology. Normally, if the data are non-stationary, the hypothesis of CSR would be rejected without further testing. In the process of developing the methodology, an alternative application of the test for CSR (the EDF) was discovered. The EDF calculation of nearest neighbor distances could have several potential uses in studying trap placement. By determining the distances between various proportions of traps (50%, 90%, and 100%) at time intervals, a quantitative picture of trap movement starts to develop and become obvious.

From June to November, the majority of traps are located less than 200 meters from the nearest trap. However, from July to September, the majority of traps are located essentially half this distance from the nearest trap (Table 3.1.). This is not really surprising because we would expect that fishermen would move all of their traps at least twice during a month's time, and that this movement would be for short distances most of the time. Also, the number of set-over-days would decrease as fishing became more productive, so traps would be hauled more often in those months. Another factor to consider is that logbook reporting increased in July (Figures 3.23. to 3.24. and Table 3.3.). This may have been due to increased fishing effort, the fishermen becoming more familiar with the logbooks, or a greater willingness to use the logbooks. Trends in trap distance may be influenced by these factors, but can still have some valid uses.

Figure 3.23. Legal Lobsters, Number of Traps Hauled, and Number of Logbook Records for Three Stonington Area Thistle Marine Logbook Units from May to December 2000.

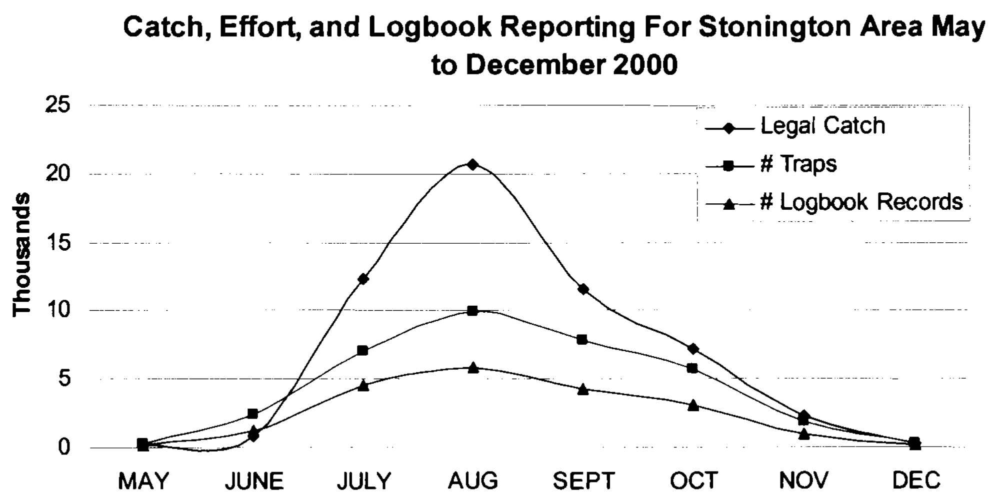


Figure 3.24. Logbook Entries (of Presence/Absence of Legal Lobsters) Recorded per Month by Three Stonington Logbook Units from May to December 2000.

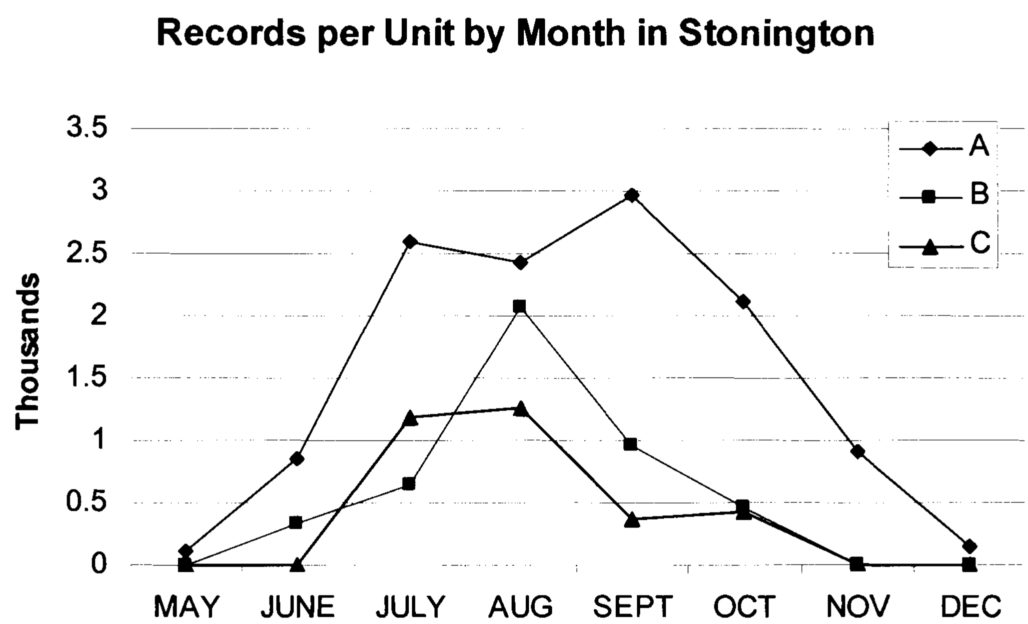


Table 3.3. Logbook Records (of Legal Lobster Presence/Absence) and Trips by Stonington Harbor Units per Month from May to December 2000.

Month	Unit A Records	Unit A Trips	Unit B Records	Unit B Trips	Unit C Records	Unit C Trips
MAY	110	1	0	0	0	0
JUNE	850	10	338	5	0	0
JULY	2596	14	655	6	1192	6
AUG	2431	16	2080	19	1267	7
SEPT	2967	23	959	13	365	3
OCT	2106	17	455	6	431	3
NOV	915	12	0	0	0	0
DEC	150	2	0	0	0	0
Total	12125	95	4487	49	3255	19

It is important to observe that the three fishermen from the Stonington area may represent the fishery in that area – that is full time and part time fishermen with large and smaller numbers of traps, respectively). The number of trips that these fishermen made (or reported) in a month indicates that this may be the case (Table 3.3.).

Monitoring trends in these nearest neighbor distances in different fishing areas and management zones might be a consequence of management decisions, economic factors, or influences on fishermen. For instance, shorter nearest neighbor distances might reflect more lobstermen entering the fishery, increases in fuel price, or even local stock depletion. These occurrences presumably would cause fishermen to place their traps closer together and reduce the overall area fished.

Nearest neighbor distances are limited in that they only measure the nearest trap, not the furthest spatial extent of traps. This measurement would be more useful in assessing factors that would cause a fisherman to extend or contract his range. A test related to the EDF is the statistic (F(x)) (Kaluzny, et al., 1998), which measures origin to point distances and would be useful for determining individual or local ranges.

Chapter 4

A GIS ANALYSIS OF MAINE LOBSTER FISHING TERRITORIES: 2000 -2001

Chapter Abstract

Thistle Marine electronic logbooks are used by a number of Maine lobstermen to collect catch and effort data while in the course of fishing. The data contributed to the Maine Department of Marine Resources database were displayed on nautical charts using GIS software to analyze the various boundaries observed by lobstermen. The areas of particular interest in this study were lobster management zones A to F, with lobstermen from Jonesport to Portland represented. Comparisons were made within zones among seasons. The fishing areas in all zones exhibited seasonal variations in size, inshore extent, and offshore extent. Management zone boundaries affected Stonington, Vinalhaven, Tenants Harbor, Spruce Head, New Harbor, and Long Island fishing areas to varying degrees in most seasons. Unofficial or territorial boundaries were assumed to have affected all areas, but some more obviously than others. Among those most affected were Stonington, Tenants Harbor, Port Clyde, Metinic, Round Pond, New Harbor, Cousins Island, and Harpswell. Territoriality among harbor gangs at least partially structured the fishing areas observed through Thistle Marine data.

Introduction

Maine Lobster Fishery Distribution

Where lobsters are caught is even more important than how they are caught. The lobster fishery in Maine occurs primarily in shallower inshore waters from approximately June through July, and then effort shifts into deeper water from August to May (Acheson, 1988; Hillman, 2003; Kelly, 1993). August through November is when the majority of the effort in the fishery occurs, coinciding with better fishing and better prices. As the weather worsens considerably from December through March, most lobster fishermen turn to other fisheries such as shrimp (Acheson, 1988). However, this is not true for the entire fishery, as lobster fishing for some occurs year round and in a variety of depths and locations (Hillman, 2003). Sometimes lobsters will trap well in deep water while most fishing is occurring in shallow areas, and at other times the converse is true. A correct statement describing the seasonal patterns of trap movement and effort for the entire fishery would be difficult if not impossible to make.

Other factors are responsible for trap placement and movement. Inexperienced lobstermen may place their traps near where a more experienced lobsterman's gear is, and they may follow his movements in hopes of having similar success. Lobstermen may avoid areas where gear is particularly congested or where a large amount of boat traffic occurs. Gear may be placed in the same area to save on transportation costs, particularly when traps are being shifted frequently to keep up with the movement of lobsters. Perhaps more importantly, informal territorial boundaries and state lobster management zones influence trap placement and movement at a larger scale.

Lobster Fishery Territories in Maine

More than a state license, the proper gear, and knowledge of where lobsters can be caught are required to go lobster fishing. A lobsterman must first be accepted by the others in the harbor he wants to fish from. The "harbor gang" may consist of lobstermen who moor their boats, buy their bait and fuel, and sell their lobsters in the same harbor or town. The harbor gang maintains an informal fishing territory for the use of its members (Acheson, 1975; Acheson and Brewer, 2003).

Territories are important to the lobster fishery for several reasons. The lobster fishery is essentially a common property resource, with rights to fishing areas and the lobsters in them held by all fishermen. Without limits, one fisherman or a group of fishermen could theoretically harvest all the lobsters. Fishermen enter into agreements both formal and informal to prevent this and to reduce the uncertainty of fishing (Acheson, 1981). The territorial system is one example of such an agreement, and it accomplishes ecological and economic goals in the fishery. It guarantees access to fishing rights for the harbor gang, helps to enforce good fishing practices (trap limits, v-notching, compliance with regulations), ensures the presence of the resource for future generations, and provides the certainty of an economic return (Acheson, 1975; 1981).

The fishing territory of one harbor gang is rarely more than 100 square miles, often not more than 10 miles from home, and contains areas of bottom that are fishable throughout the year (Acheson, 1975:187). A territory may actually be several areas, and border on territories fished by several other gangs. The boundaries of the territory are often marked by minor features that are familiar only to people who know the area. These features may be landmarks like islands, ledges, trees, channels, or edges of bottom (Acheson, 1975). Observance of these boundaries varies with distance from shore. Close to shore they are known to the foot, whereas offshore they are more variable. In the winter, less competition and harder to define, offshore landmarks contribute to mixed fishing (Acheson, 1975).

Enforcement of these boundaries is accomplished in many ways, few of them legal. An intruder's trap may be hauled, the lobsters removed, the buoy placed inside, and the trap thrown overboard. The buoy and warp may just be cut off, but in more rare and extreme cases, verbal threats, boat destruction, or other sorts of altercations may be the result of the violation of territorial boundaries (Acheson, 1975; 1998; Acheson and Brewer, 2003).

These boundaries have many variations, but Acheson (1975; 1988) identified two general forms of these informal territorial boundaries. In the first type of territory, the "nucleated" territory (Acheson, 1988:79), resistance to intruding traps becomes stronger closer to the home harbor. Mainland harbors generally exhibit this kind of territory, with the center of the area being the harbor itself. Defense of the territory weakens once outside the harbor mouth. The edges of these nucleated territories are therefore less well defined and mixing of gear from several different harbor gangs may occur, particularly in the winter when areas of deeper water are fished by men from at least two different harbors. Invaders of this type of territory might meet with less resistance if the territory is held by multiple harbor gangs (Acheson, 1975).

The second type of territory is the "perimeter-defended" territory, which is held mostly by lobstermen who fish around offshore islands such as Monhegan and Metinic (Acheson, 1975:190). Traps fished by fishermen from other harbor gang are not permitted inside this well-defined boundary. The notion of ownership does not decrease with distance from the home harbor or during the winter season. The idea of 'staying on your own side of the line' is very strong. In this type of territory, claims over ocean areas are connected with formal ownership of land (Acheson, 1975: 190). Rights to water territory may be rented out when not in use by the owner of the island property. In the past, most territories were perimeter defended, but with various changes in the fishery over time, most harbor gangs could not or would not defend their territory's boundary. The cost of strong resistance to encroachment would only benefit the members of the gang who fished closer to the harbor or center of the area because their gear would not be put at risk (Acheson, 1988).

An important difference between nucleated and perimeter-defended territories is the level of resistance to newcomers to the harbor gang. It is much easier to gain entrance to a harbor gang that fishes a nucleated territory. If a fisherman is a resident of the community and gets along with local practices, he will eventually gain acceptance. It is much more difficult to enter the gang of a perimeter-defended area. They have put much more effort into maintaining their boundaries, and this effort would not be worthwhile if just anybody could come and join the gang (Acheson, 1975). A fisherman may have a chance if he is willing to live on the island and become part of the community, but this may only occur if his family has summered there or has owned land in the past.

Changes in Territoriality

Territories in the early 1900's were mostly perimeter-defended due to the limitations of the boats used at the time. Lobstermen used sloops or dories and only fished during the summer. As a result, the territories were small and small groups defended them vigorously (Acheson, 1975: 192). A lobsterman who owned land along the shore considered it his right to fish the adjacent waters and protected that right zealously. Most areas are now nucleated, and this is due in no small part to technological change. More seaworthy boats, motors, and depth-finding equipment increased the range a lobsterman could fish. The existence of two different types of boundaries is also due to political factors. "Boundary breakdown or maintenance is the result of conflict and political pressure" (Acheson, 1975: 193). This pressure came from fishermen who lived in estuarine areas where lobsters are not available year-round, who wanted to fish in the open-ocean territories maintained by coastal harbor gangs. These fishermen were willing to invade these territories because they had the ability to form "political teams" and did not have desirable income alternatives (Acheson, 1975: 193).

Within the two types of territories, boundaries can be arbitrary and are subject to small changes. The boundaries of many territories undergo small shifts over time, and this change occurs when a group of fishermen from a harbor gang place their traps in the territory of another gang and can keep them there (Acheson and Brewer, 2003). It is rare for a single fisherman to effect the movement of a local boundary because of the gear it may cost him to intrude. It generally requires a team recruited from the harbor gang to defend a line or to move it (Acheson and Brewer, 2003). However, an older, more experienced fisherman who is well known in the area may be able to disregard some boundaries with impunity, while a newcomer or younger fisherman would face immediate reprisal. This is because the older fisherman most likely comes from a large, well-known family and thus has more allies (Acheson and Brewer, 2003: 44).

In perhaps the largest change in lobster management history, a zone management system was created in 1995 (Acheson, 1997; Acheson, et al., 2000; Acheson and Brewer, 2003; MEDMR, 2001). The Maine coast was divided into seven management zones (A –

G) with defined boundary lines separating them. Each zone has different rules on how many traps can be fished, when fishing occurs, and how many licenses are allowed. Trap limits are the same for all zones (800 traps per license) except for zone E, which passed a trap limit of 600 (Acheson, et al., 2000). Swans Island and Monhegan Island have state enforced conservation zones placed around them and have different trap limits and seasons within these zones (Acheson, 1998). A limited-entry law was passed in 1999, giving the zones power to establish and in/out ratio, which five of the seven did in 2000 (Acheson and Brewer, 2003). These regulations and other recent changes in fishing practices have combined to increase trap congestion as full time fishermen place more traps in greater areas further from their home harbors.

Acheson and Brewer (2003) identified four important changes to the territorial system that have occurred in the past decade. The first change has been a shift in effort to offshore fishing areas which have never been part of the territorial system. Fishermen are placing large numbers of traps in these waters throughout the winter. There has been no attempt to bring the territorial system into effect here. Secondly, the amount of mixed fishing in the western parts of the coast is increasing, and the amount of exclusive fishing bottom is decreasing. The trend of fishermen from upriver areas fishing the open-ocean areas in the winter has continued and increased. The number of full time fishermen with large gangs of traps in towns like Wiscasset and Bremen has increased, and the trend is now towards large mixed fishing areas. A third change has been contraction of the island fishing areas as a result of increasing pressure from mainland fishermen who will sacrifice a lot of gear to gain additional fishing space. The exceptions are Swan's Island and Monhegan, which have exclusive, legal fishing rights to their territories. The fourth change has been increasing government involvement in imposing boundary lines. The zone management law caused many changes in local boundaries. Some traditional boundaries were reinforced while others were effectively removed, either allowing fishermen access to areas they traditionally had been denied, or denying access to areas traditionally fished.

Territory Research

In past studies, these boundaries were recorded on hand-drawn maps using observations and conversations with members of different harbor gangs. Several areas in midcoast Maine, where these types of boundaries are well defined, have been studied intensively. We do not have information on the distribution of fishing effort along these boundaries throughout the year. That is, we do not know where the majority of traps are placed in each month of the year. Current information in time series concerning these boundaries would be useful for observing trends in boundary movement. Changes in these territories from earlier studies could be used to inform future management decisions, economic analyses, or population dynamics models.

Lobstermen are becoming more willing to share information and allow state lobster biologists onboard their boats with programs such as the Maine Department of Marine Resources (DMR) sea sampling program increasing in size and coverage (Wilson, et al., 2001). Partially in response to this willingness, an existing type of technology has been recently implemented in the lobster fishery in the form of electronic logbooks. Thistle Marine, LLC initially marketed the logbooks as a tool for lobstermen to increase their efficiency and profit through a confidential internet reporting system. A lobsterman could input his fishing trip data into the logbook in a trap-by-trap format, and on returning to the wharf, upload the data to the company's web server. Paper reports of his fishing activity would arrive in the mail, or he could view the same information on the web in an interactive format. Originally these data were only shared between the lobsterman and the company until DMR approached Thistle Marine about establishing a data-sharing program. Lobstermen who volunteered for this program would have a logbook installed on their boat, paid for by DMR, in return for allowing their fishing data to be entered into a state maintained database. The confidentiality policy is the rule of three's, where specific data points representing less than three lobstermen can not be publicly displayed.

An important aside should be mentioned here. Logbook users in general tend to be the more successful fishermen in their areas and are not new to the lobster fishery. They also seem to have a willingness to cooperate with scientists and take an active interest in conservation and management of the resource they use. These factors would lead us to believe that the fishing practices of these lobstermen would perhaps be different from others in their respective harbor gangs. If a logbook user were to temporarily adopt more aggressive trap placement tactics, we could not be certain that the trap data would be recorded. Thus the logbook data does not necessarily reflect the fishing practices of the fishery as a whole, but rather most likely represents only a specific part of the fishery.

The Thistle Marine/DMR logbook database was established in May 2000, and includes data through December 2001. One of the unique characteristics of this data is that each individual trap or string of traps has latitude and longitude coordinates associated with it. These data can be viewed on a nautical chart to observe where the traps are placed. A logbook unit identification number is assigned to each lobsterman who volunteers his data, and this number is included in each trap record. For the purposes of this study, the information in the Thistle Marine database can be used to observe these official and unofficial boundary lines or territories. Fishing activity from all months of the year in which data were recorded can be observed, and territoriality can be compared among fishing seasons.

Methods and Materials

Thistle Marine electronic logbooks are used by a number of Maine lobstermen to collect catch and effort data while in the course of fishing. The first trip was recorded on May 30, 2000, by a lobsterman in Penobscot Bay. Since that time, Thistle Marine LLC and the Department of Marine Resources (DMR) have expanded the logbook program to include lobstermen from Maine to Massachusetts. Over one hundred logbooks have been sold to lobstermen and the DMR, with at least 60 units contributing data to DMR's database. This database currently includes trips recorded from May 2000 to December 2001 with approximately 80,000 entries. The data are recorded in the logbook for each trap or string of traps hauled. The data include logbook unit number, trip number, lobster market category id number (legal, short, oversize, berried, v-notched, berried with v-notch), date and time, longitude, latitude, amount of lobsters caught, number of traps hauled on a string, and the ten minute square location of the traps. Logbook records can be plotted as data points in GIS software. We used ESRI's © ArcView 3.2a linked to the data located within an MS Access© database to perform the analysis.

The database was queried to select data collected during specific seasons that reflect levels of activity in the fishery. The seasons were as follows: August 2000 to November 2000, December 2000 to March 2001, April 2001 to July 2001, and August 2001 to December 2001. December 2001 was added to the August to November season because it was the last month of data available. The data points for each season were displayed in separate ArcView projects (a project is the method of grouping data sets together to be displayed on one map) as unique symbols to identify each unit number. The points were plotted over a nautical chart layer (MapTech© chart# 13260.1 bsb). The units were associated with harbors using an address list and information obtained from Thistle Marine and DMR.

An Arcview script was downloaded from ESRI's© website that draws a polygon around selected points in a view (Butgereit, 2000). Using this script as well as the polygon drawing tool, polygons were drawn around data points recorded by fishermen from a single harbor. The polygons were color and pattern coded to differentiate among harbors. Themes were created for each harbor in each season that contained the polygons. The harbor polygons were framed by lobster zone (A-F) in layout form and exported to picture format. The export format obscured some boundary overlaps that were transparent in the project view, so approximations were necessary. Visual analysis of the polygons was used to make qualitative observations on the various boundaries observed by the fishermen. Comparisons are made within zones among seasons. The areas of particular interest in this study were management zones A to F, with fishermen from Jonesport to Portland represented.

Results

Seasonal fishing patterns and the observance of official and unofficial boundaries were detected. No data were available in Zone A until the August to December 2001 season (Figure 4.1.). Fishermen from Jonesport and Milbridge collected data during this time. Their fishing areas did not overlap or display any distinct zonation or unofficial boundaries. Data apparently collected by a fisherman from Stonington were from traps located within the Milbridge fishing area. This may be an error in the data and could not be verified at the time.

Logbook usage varied widely in Zone B. Data from Bar Harbor were collected in the August to November 2000 season (Figure 4.2.). The zone boundary did not seem to affect the fishing area, and the western edge overlapped the Seal Harbor area seen in April to July 2001 (Figure 4.3), and in August to December 2001 (Figure 4.1.). No data were collected in the December 2000 to March 2001 season. Seal Harbor was the only harbor represented in April to July 2001 (Figure 4.3.). However, in August to December 2001, Seal Harbor's fishing area overlapped slightly with Southwest Harbor (Figure 4.1.). When traps were moved offshore, the two areas were widely divergent. Data collected by a different Stonington fisherman (than the one apparently fishing the Milbridge area) were located in the Southwest Harbor area. This may be more plausible because of the shorter distance from Stonington, but again the data could not be verified.

Figure 4.1. Management Zones A and B: Logbook Record Areas by Harbor from August to December 2001.

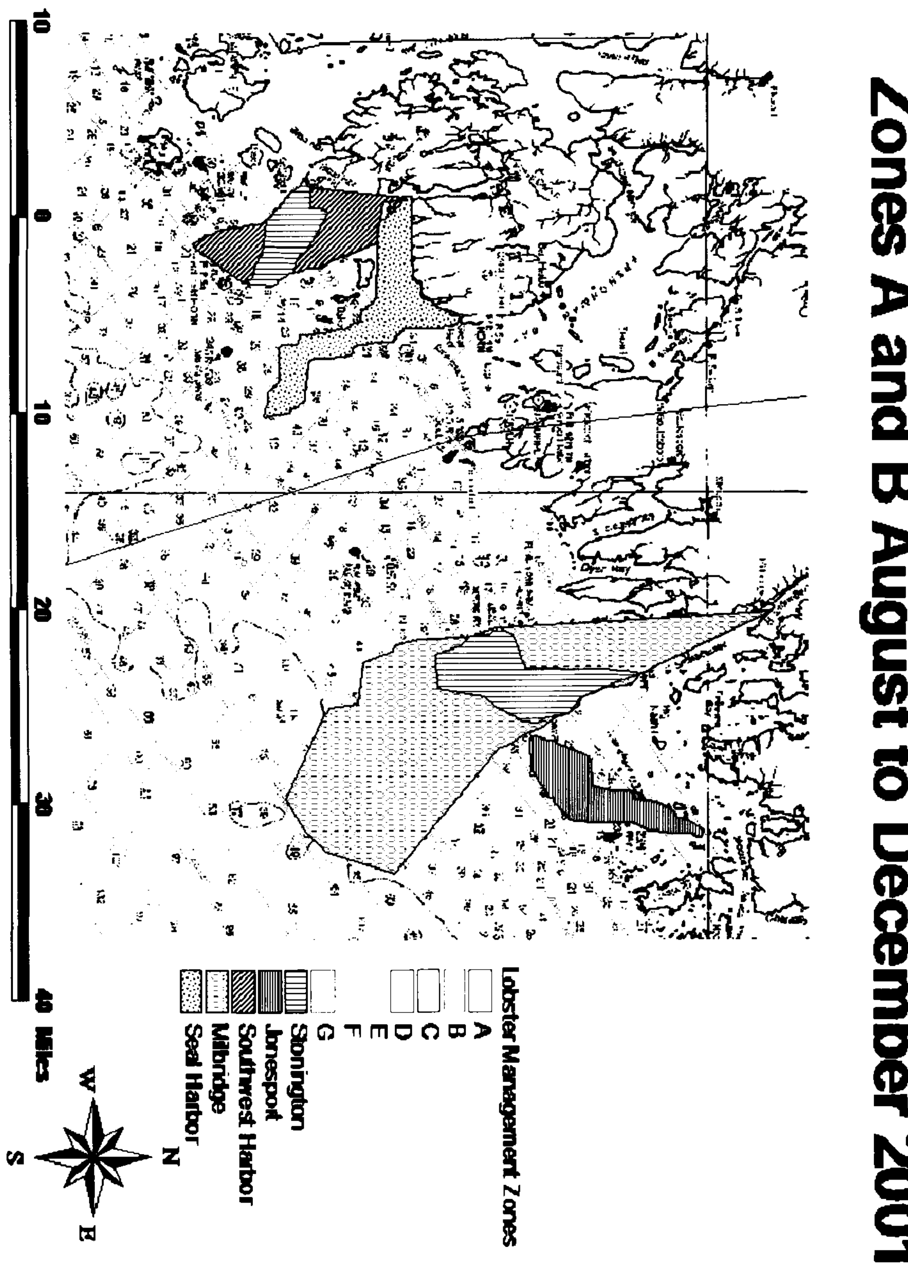


Figure 4.2. Management Zone B: Logbook Record Areas by Harbor from August to November 2000.

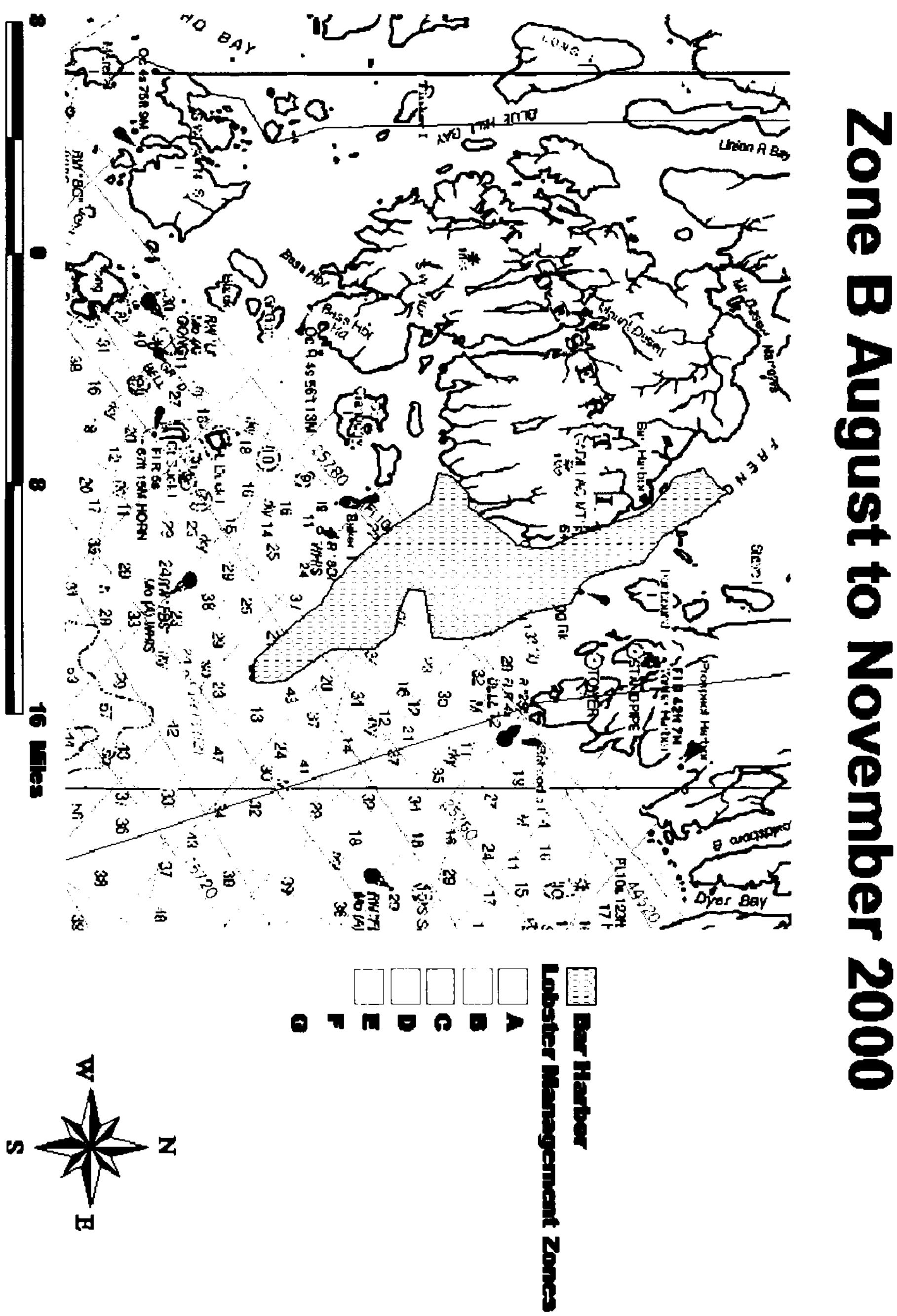
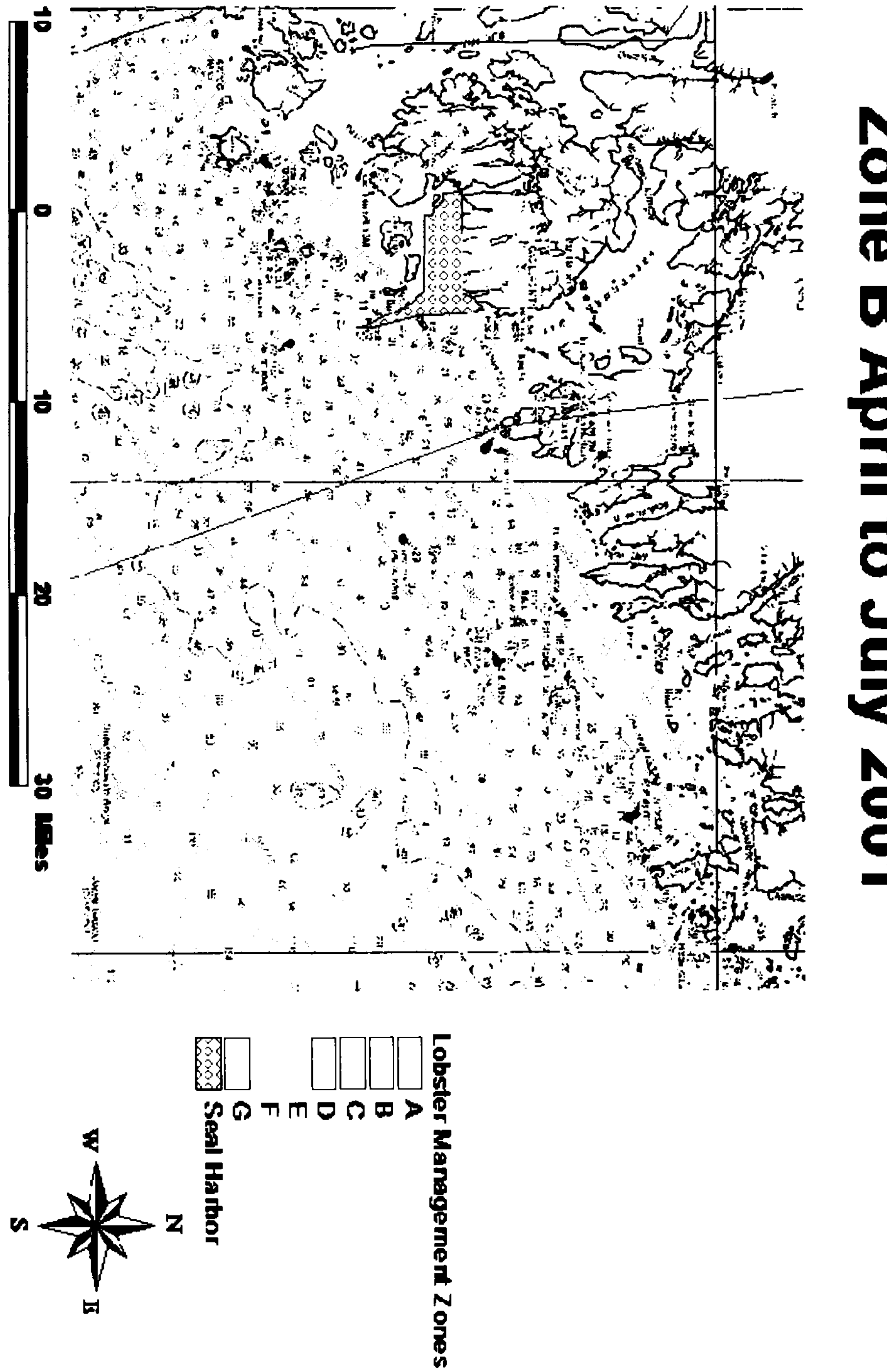


Figure 4.3. Management Zone B: Logbook Record Areas by Harbor from April to July 2001.



The Zone C fishing areas were more stable over time, though several new logbook users started collecting data in the Stonington area over the study period. The Stonington area is very much constrained by the zone boundary on the east and by the Isle au Haut area on the west (Figures 4.4. through 4.6.). The only seasonal variation was seen during the December 2000 to March 2001season when only occurred offshore (Figure 4.7). During the other three seasons, fishing occurred in relatively the same spatial extent (Figures 4.4. through 4.6.). The offshore areas maintained the narrow extent and did not broaden out. Data from the Vinalhaven area were collected in August to November 2000 and in April to July 2001 (Figures 4.4. and 4.5.). The area was constrained by the zone boundary on the southwest edge and did not change appreciably in extent. A Tenants Harbor fishing area was located within the zone C boundary around Matinicus in the August to December 2001 season (Figure 4.6.).

Figure 4.4. Management Zone C: Logbook Record Areas by Harbor from August to November 2000.

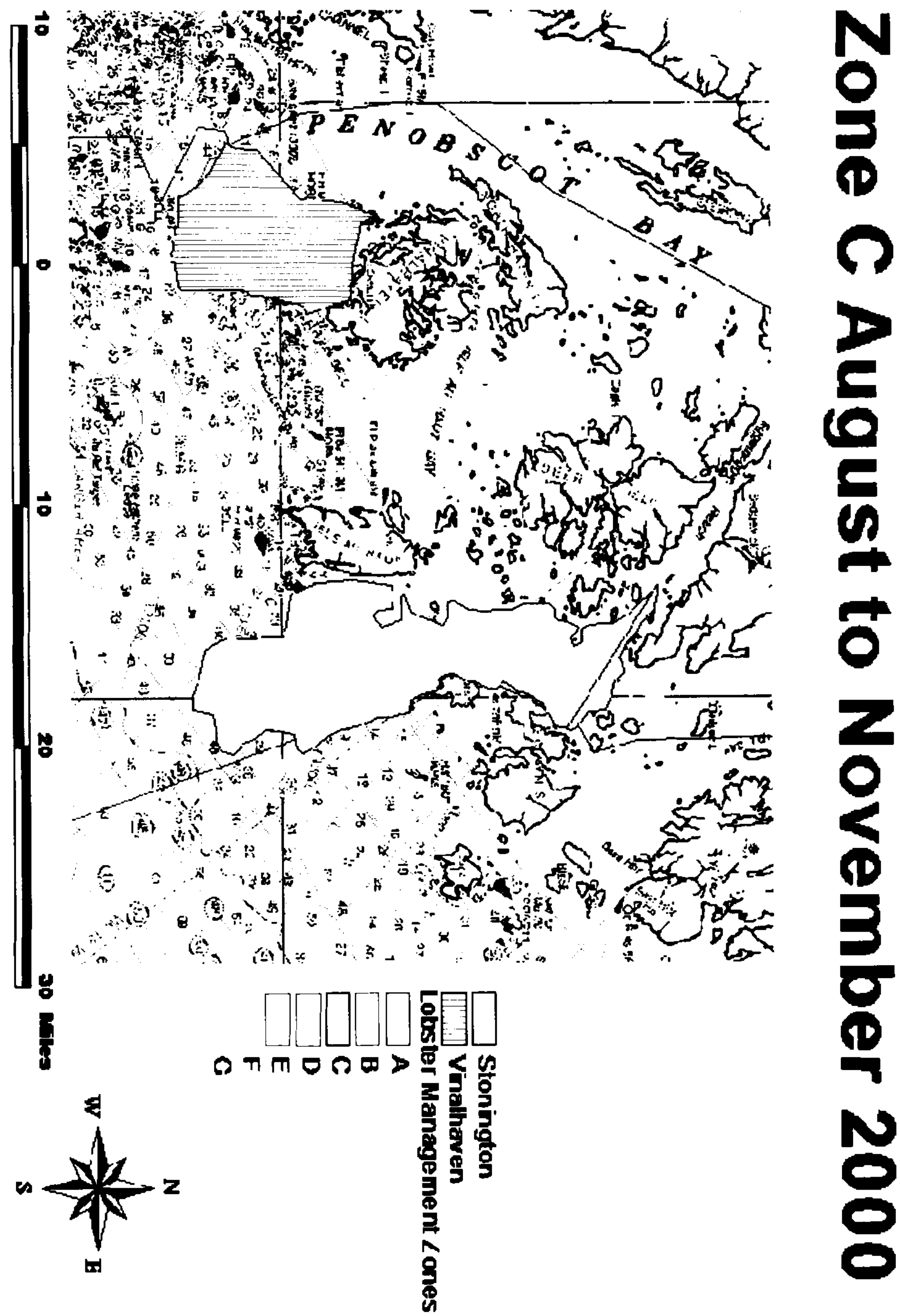


Figure 4.5. Management Zone C: Logbook Record Areas by Harbor from April to July 2001.

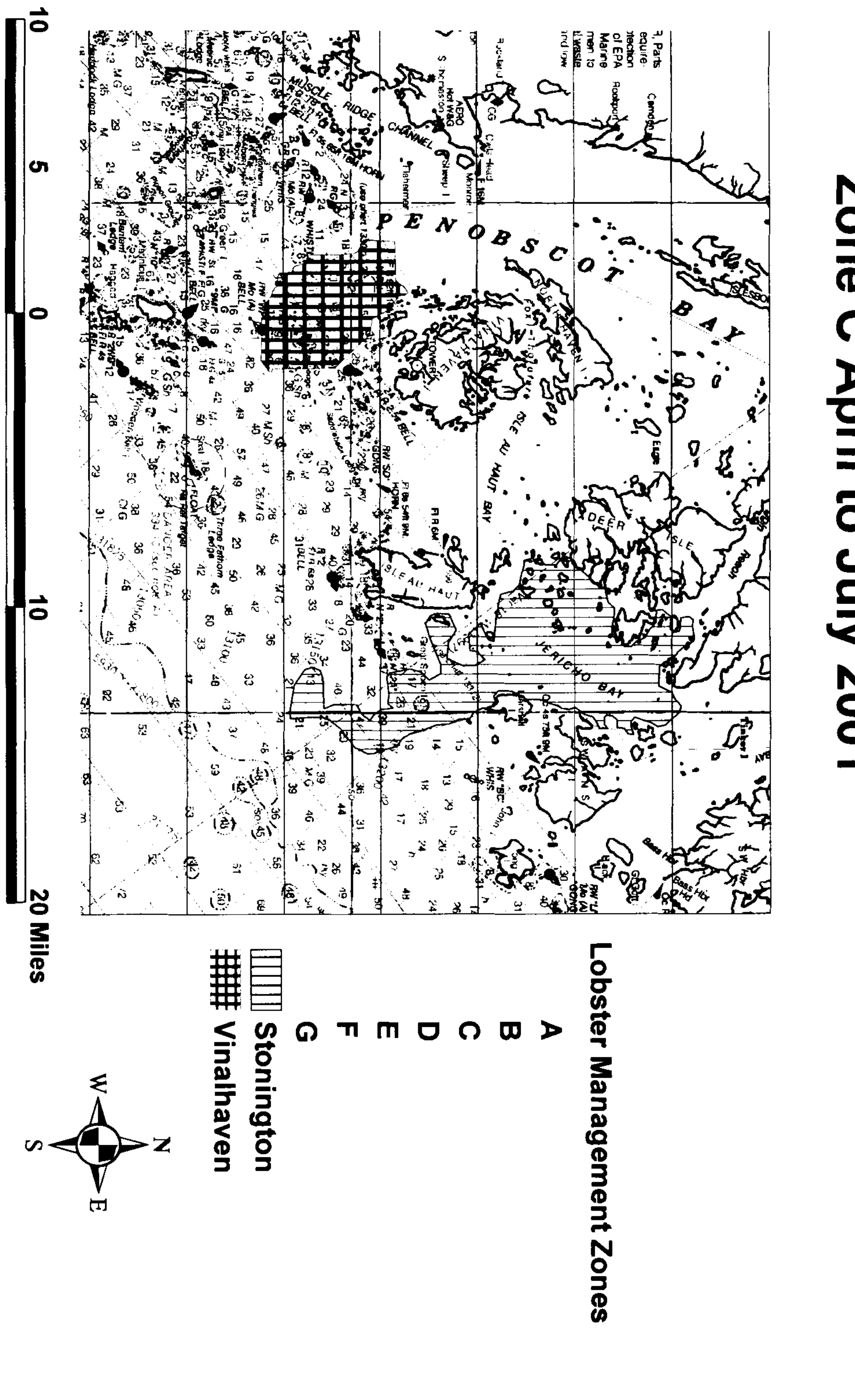


Figure 4.6. Management Zone C: Logbook Record Areas by Harbor from August to December 2001.

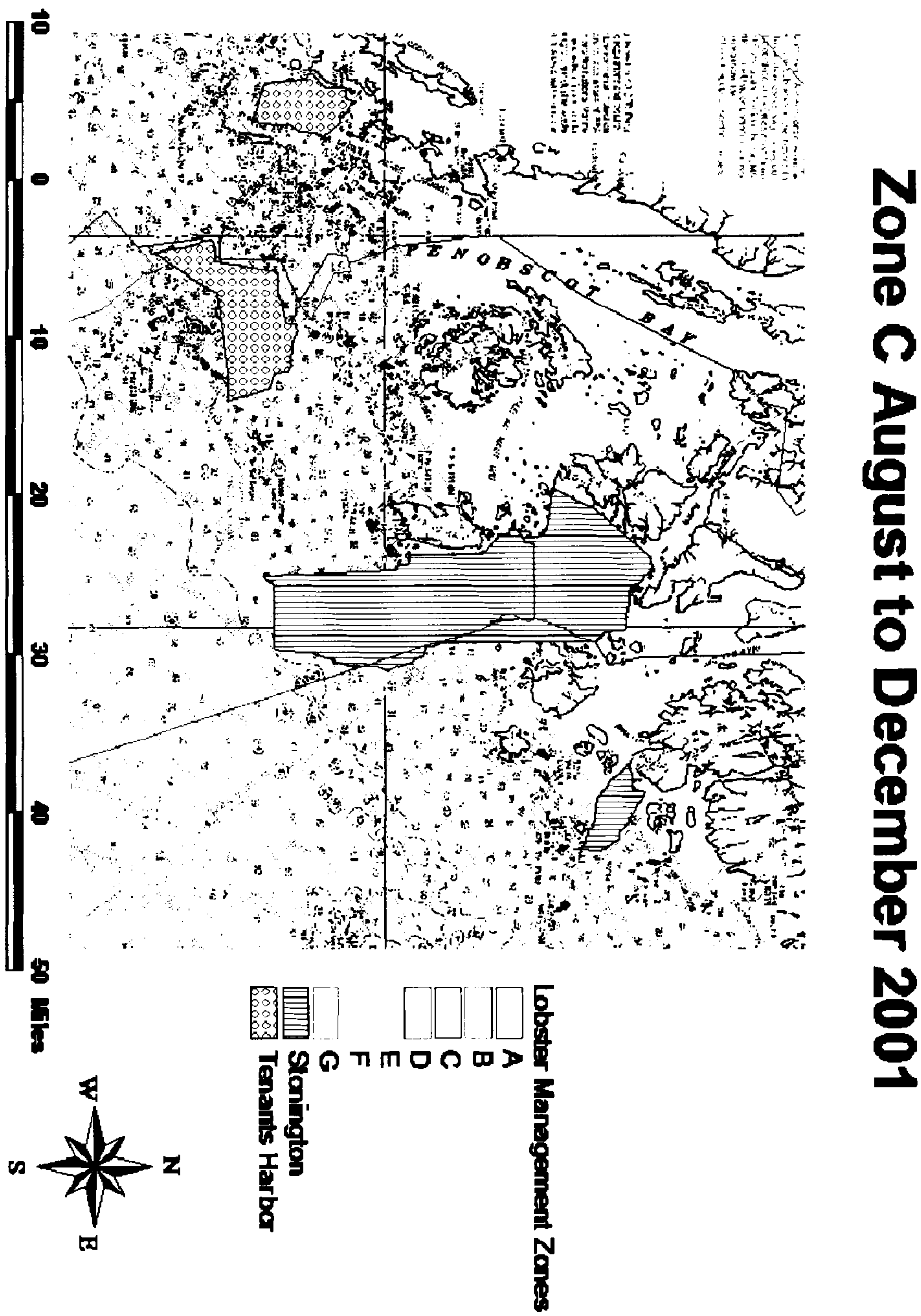
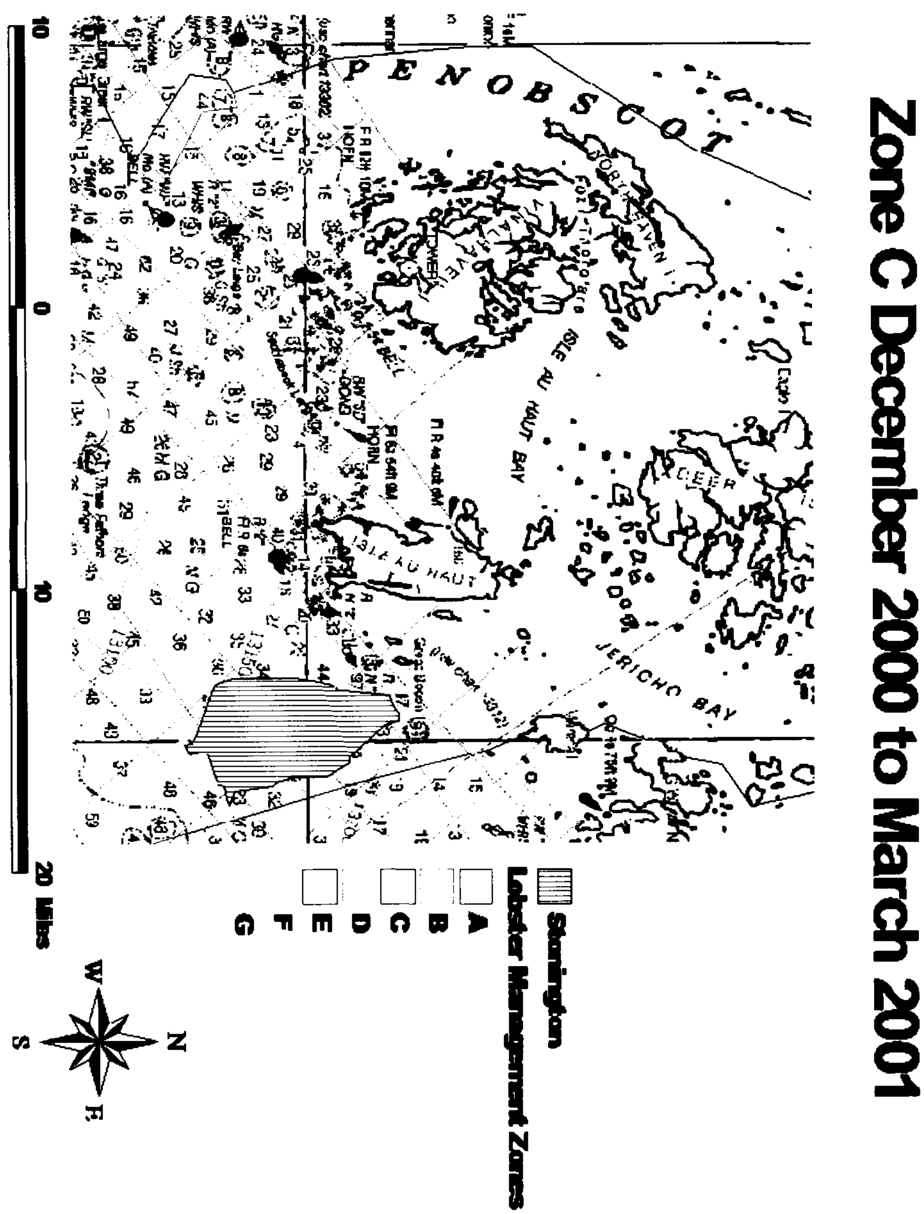
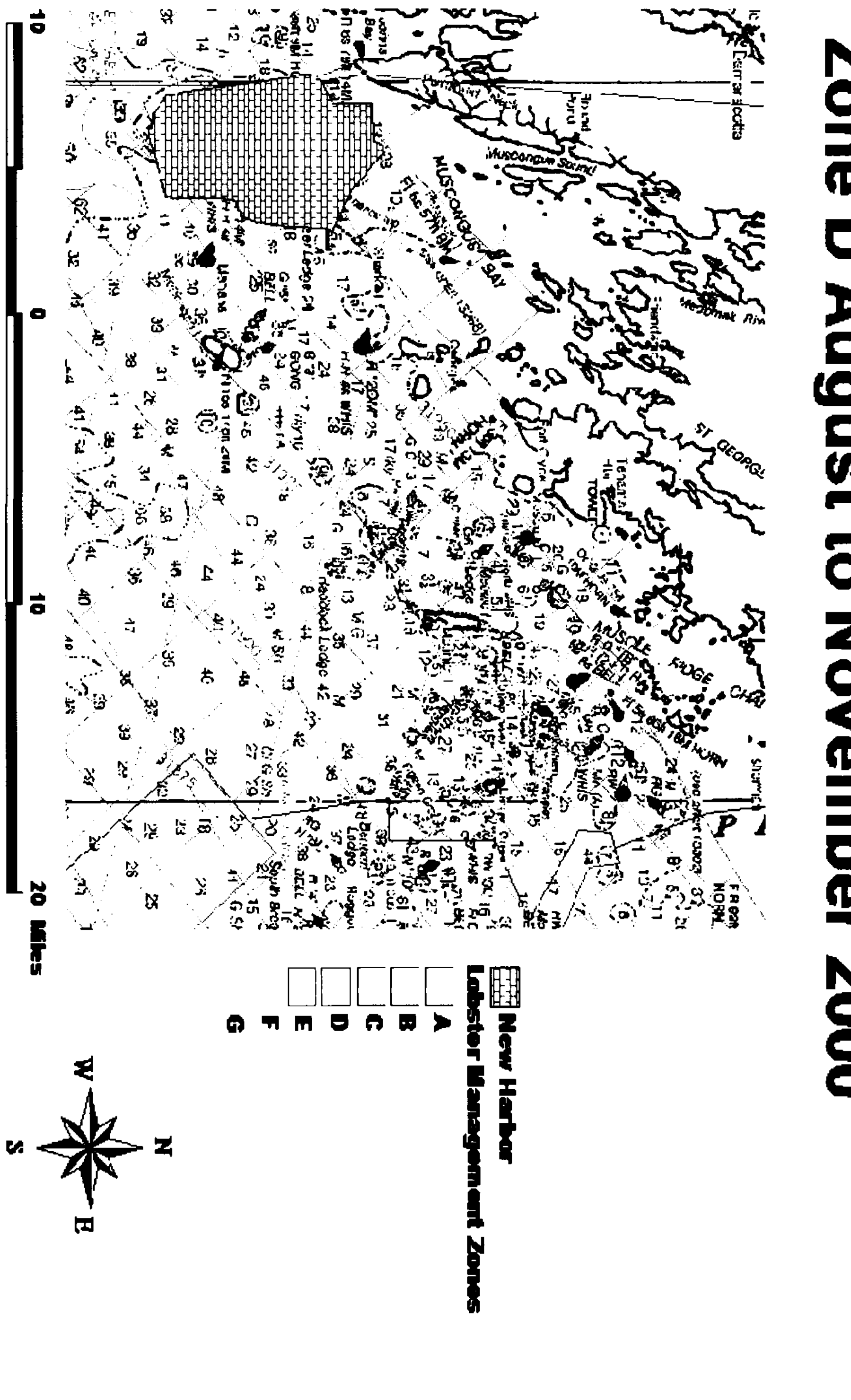


Figure 4.7. Management Zone C: Logbook Record Areas by Harbor from December 2000 to March 2001.



Fishermen from New Harbor, Round Pond, Tenants Harbor, Port Clyde, Spruce Head, and the island of Metinic collected data at various times over the study period in Zone D. New Harbor data were available in August to November 2000 (Figure 4.8.) and in December 2000 to March 2001 (Figure 4.9.). The zone boundary on the west side was followed well offshore, but no line seemed definable on the east side. The Round Pond fishing area in August to December 2001 (Figure 4.10.) appeared to overlap the New Harbor area. The Round Pond area was well defined on the west side.

Figure 4.8. Management Zone D: Logbook Record Areas by Harbor from August to November 2000.



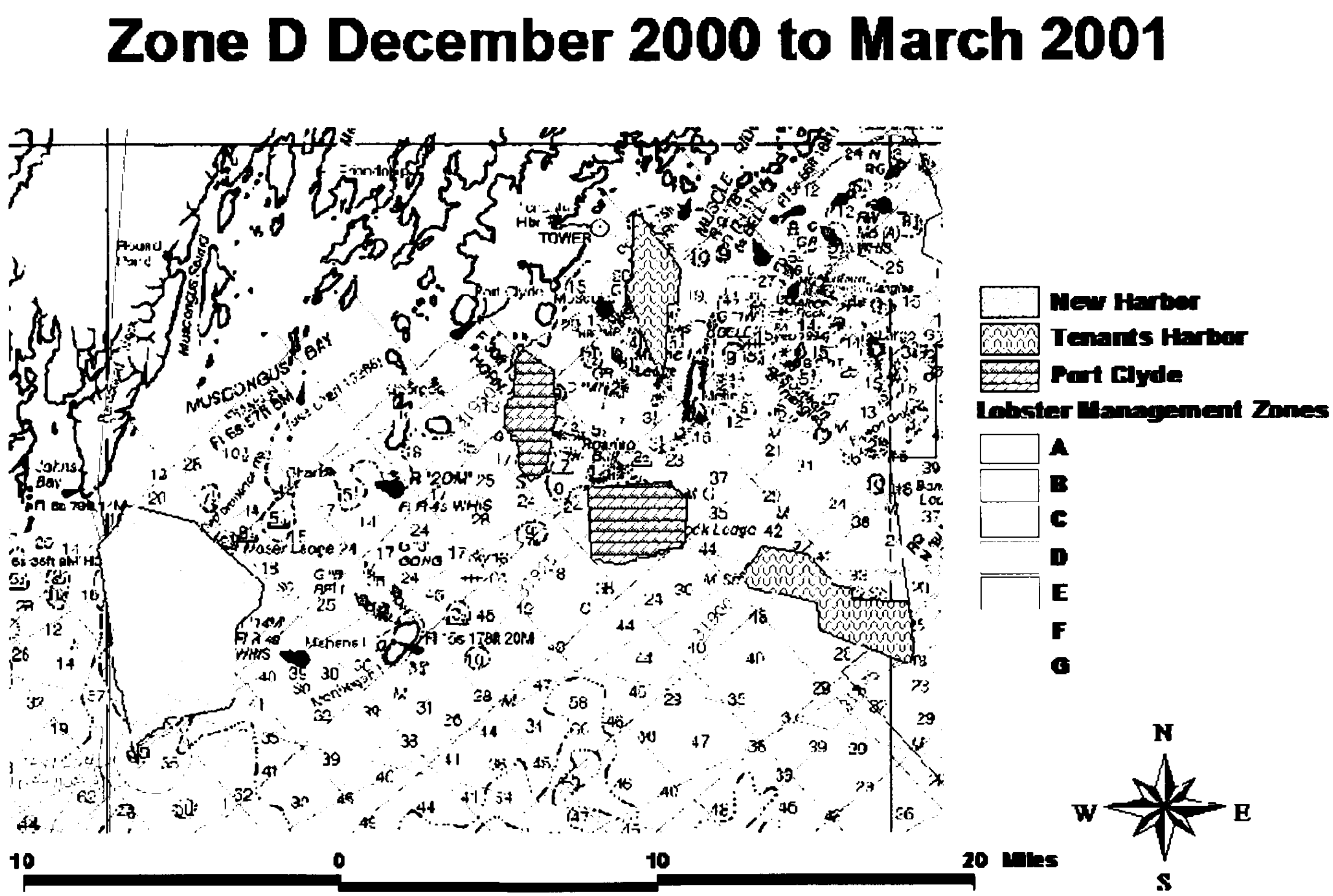
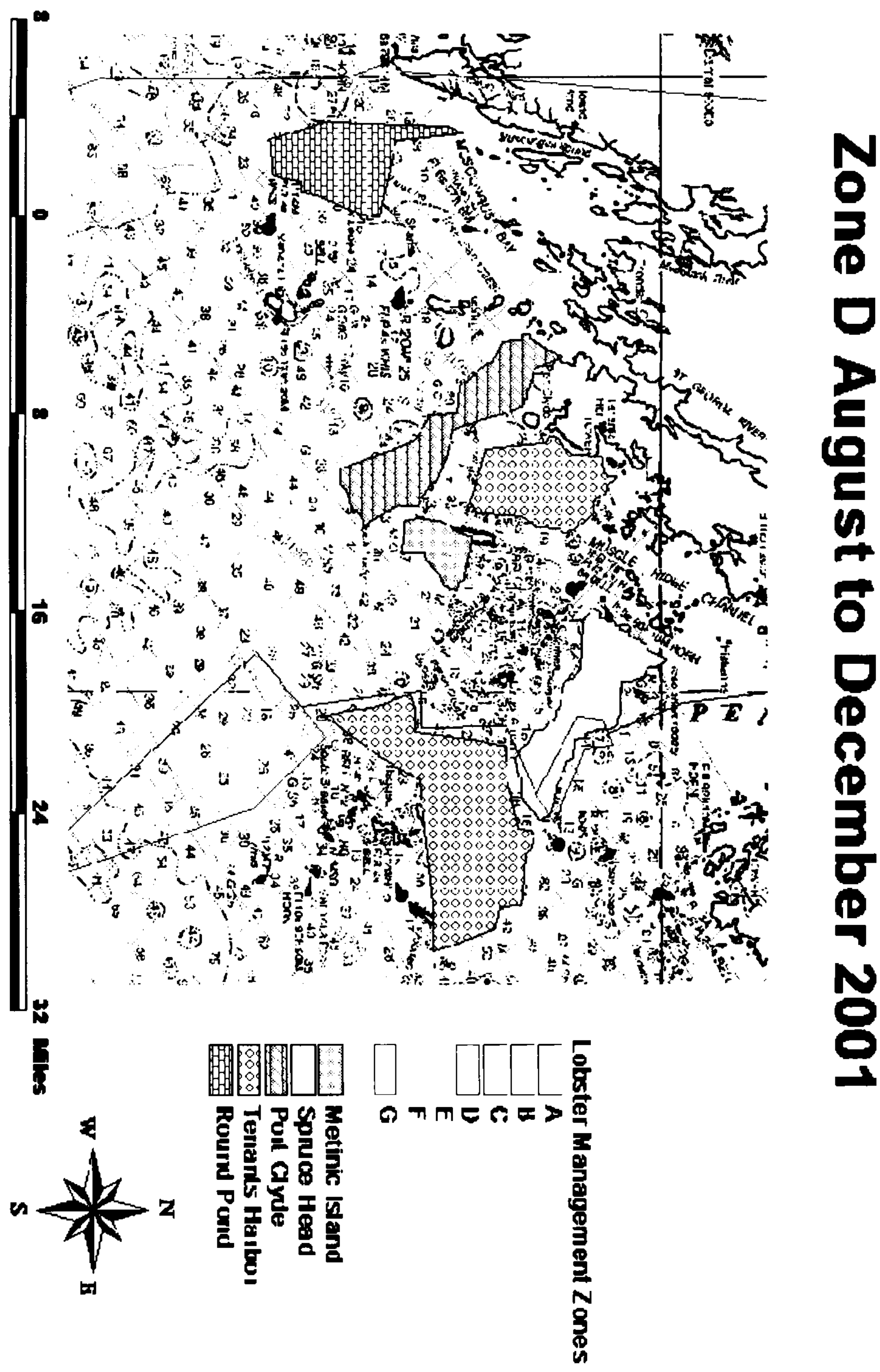


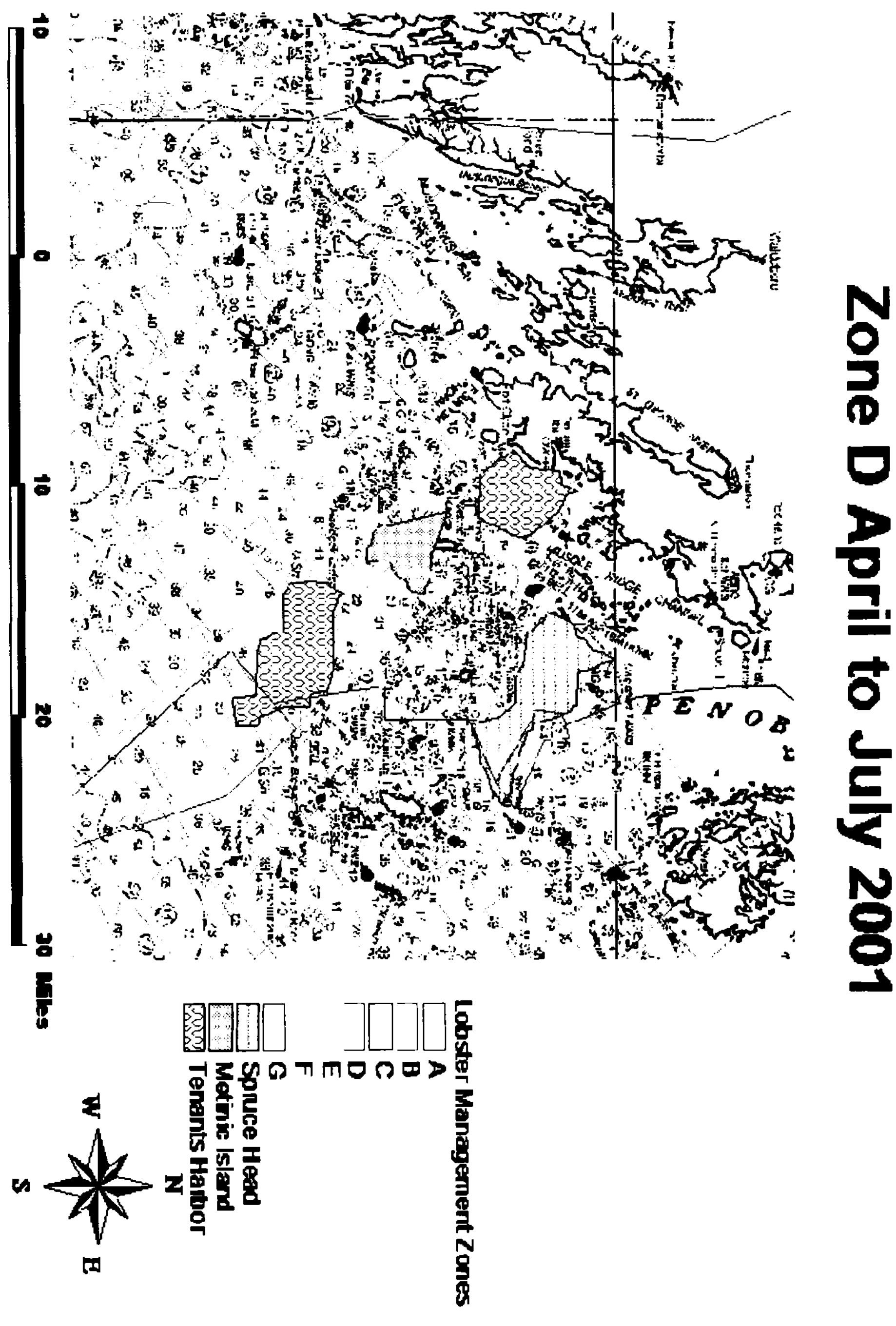
Figure 4.9. Management Zone D: Logbook Record Areas by Harbor from December 2000 to March 2001.

Figure 4.10. Management Zone D: Logbook Record Areas by Harbor from August to December 2001.



The east side of the Zone D area showed stricter boundary observation. Tenants Harbor areas were in two discrete locations from December 2000 to December 2001(Figures 4.9., 4.10., and 4.11.). No overlap occurred with the Port Clyde, Metinic, or Spruce Head fishing areas. The one anomaly was the August to December 2001 season when Tenants Harbor data were located in Zone C (Figure 4.10.). No overlap occurred among the other fishing areas, and the Metinic fishing area was restricted to the waters directly around the island.

Figure 4.11. Management Zone D: Logbook Record Areas by Harbor from April to July 2001.



No logbook users fished in Zone E, and Zone F was the furthest area west investigated in this study. The Phippsburg fishing area was represented in each season, and while the inshore and offshore extent to which fishing occurred varied, the west and east boundaries remained relatively constant (Figures 4.12. through 4.15.). The August to December 2001 season was an exception with the fishing area greatly reduced due to sparse data collection during this season (Figure 4.15.). Cousins Island and Harpswell fishing areas were adjacent in August to November 2000 (Figure 4.12.), and overlapped slightly from April to December 2001 (Figures 4.14. and 4.15.). The Long Island fishing area extended further offshore than the other areas in August to December 2001, while the inshore part overlapped the Cousins Island area (Figure 4.15.).

Figure 4.12. Management Zone F: Logbook Record Areas by Harbor from August to November 2000.

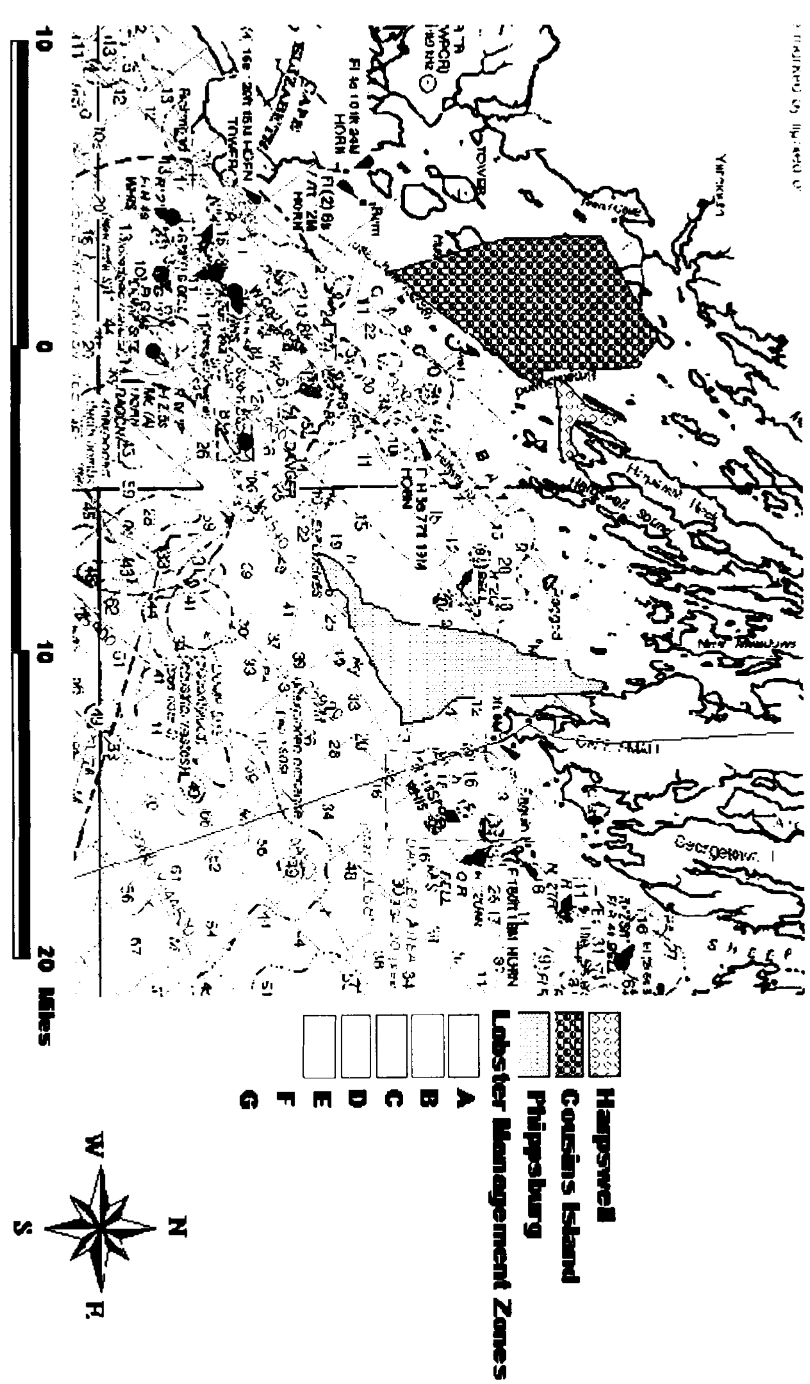


Figure 4.13. Management Zone F: Logbook Record Areas by Harbor from December 2000 to March 2001.

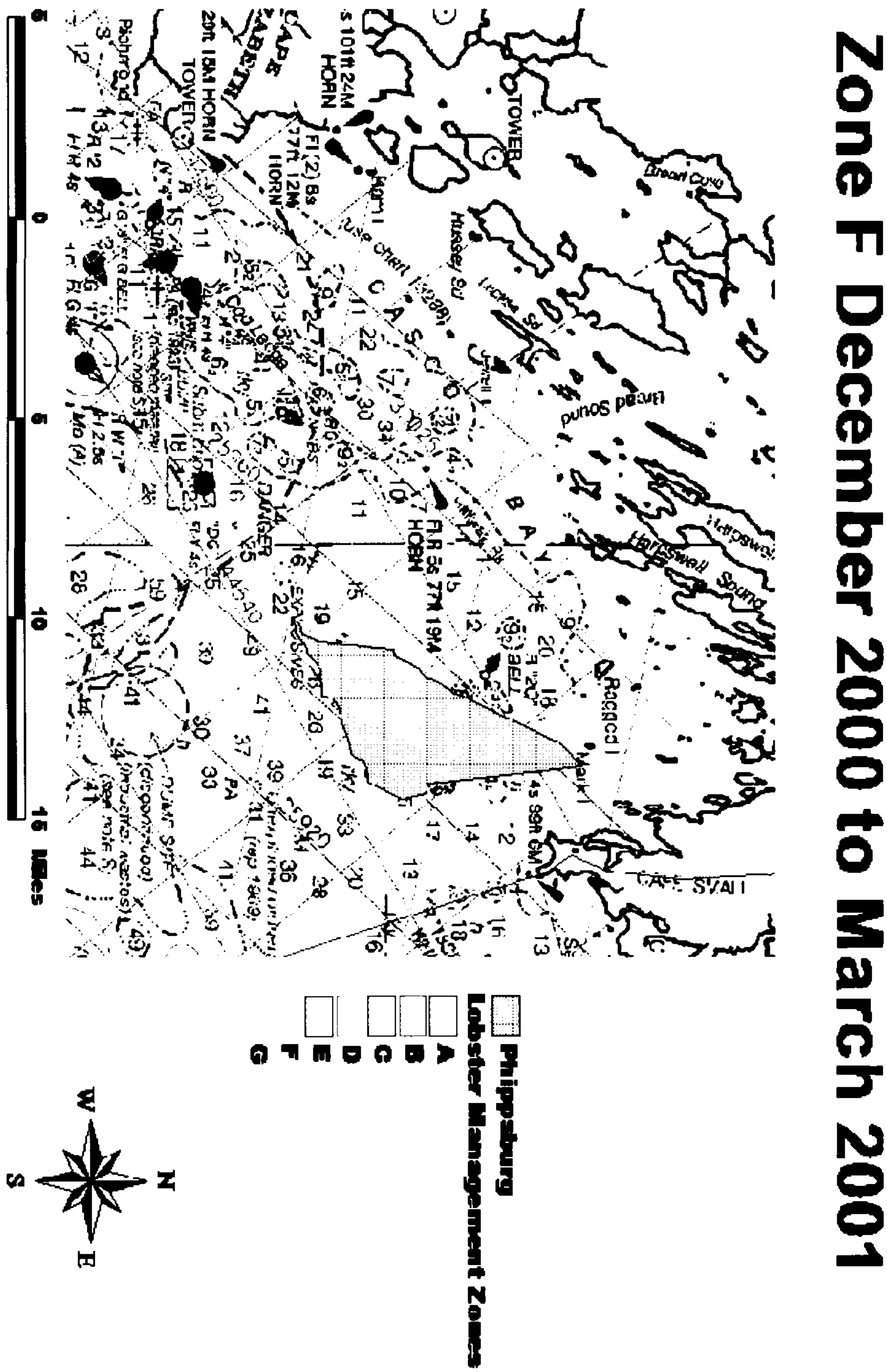
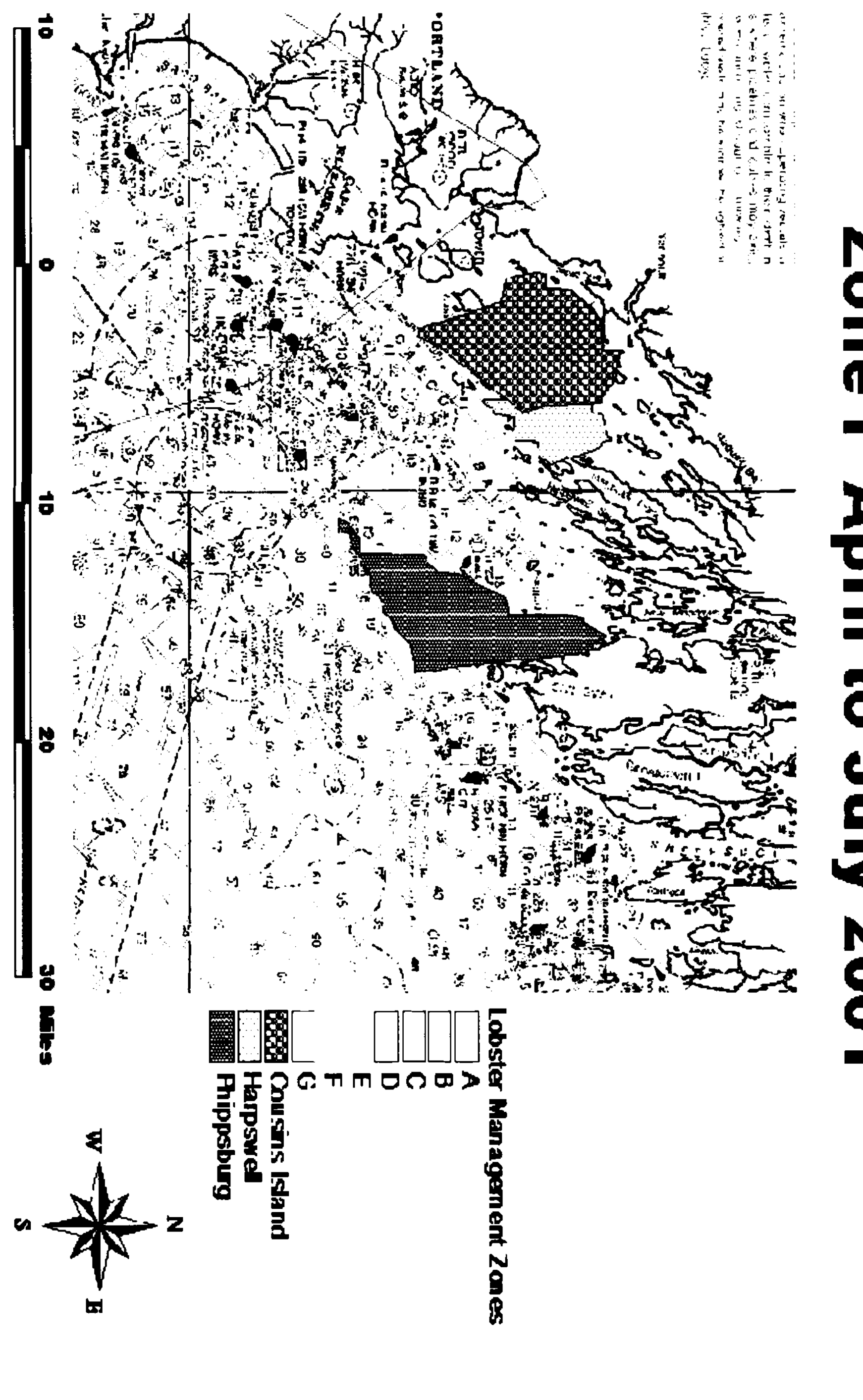


Figure 4.14. Management Zone F: Logbook Record Areas by Harbor from April to July 2001.



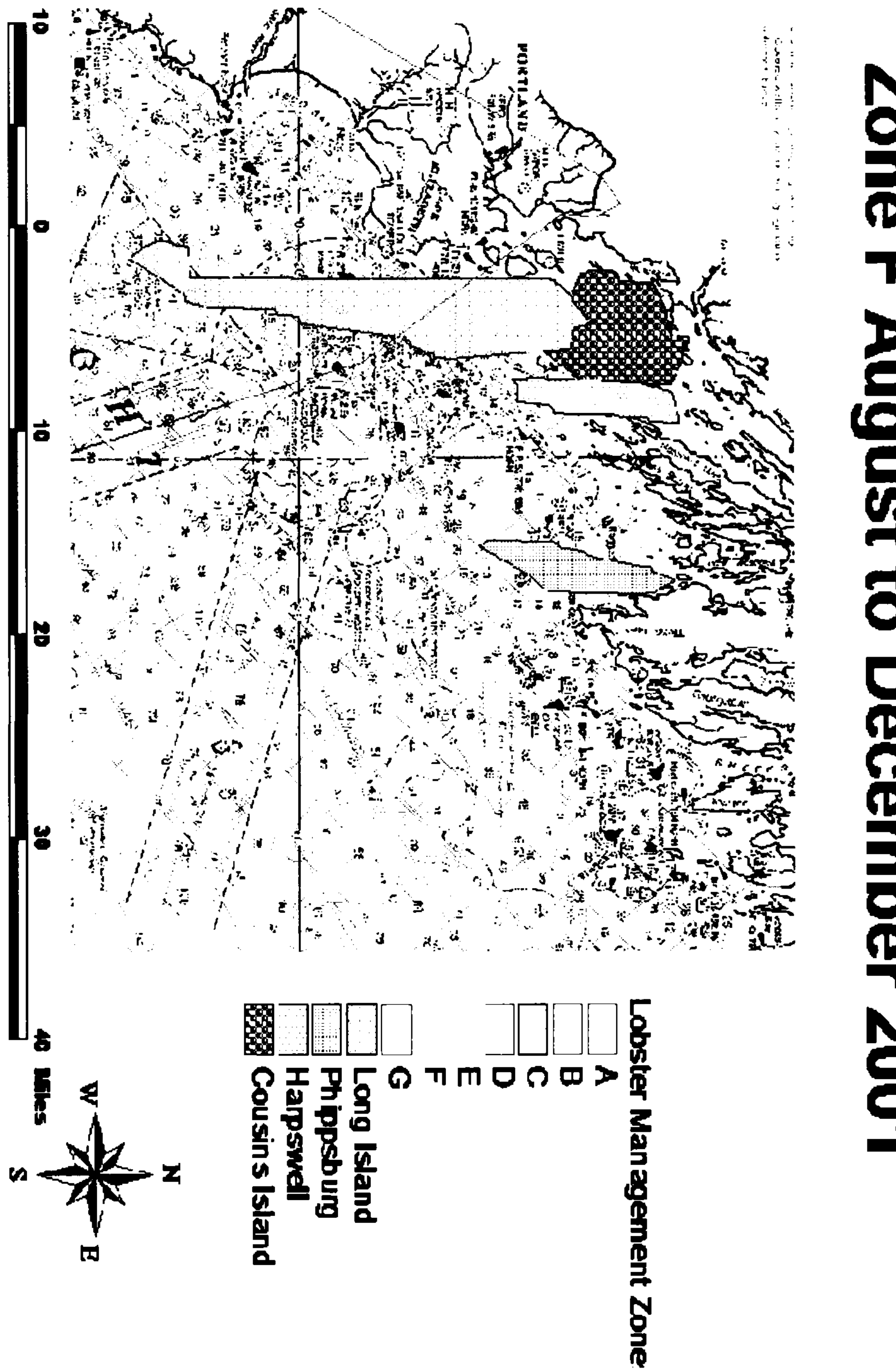


Figure 4.15. Management Zone F: Logbook Record Areas by Harbor from August to December 2001.

Inconsistencies in the collection of data resulted in uneven temporal coverage of the harbors. Few harbors were represented in all seasons. Some users fished in the winter months while others did not, and new logbook users started collecting data while other users stopped using the logbooks over the time period of this study. In addition, some of the data were located in areas that did not remotely match the address of the logbook user and were excluded from the maps. This occurred in one instance of a user located in Bass Harbor whose data were located in the Tenants Harbor fishing area. Possible errors in the database contributed some confusion as to whether fishermen really recorded data in some areas.

The fishing areas in all zones exhibited seasonal variations in size, inshore extent, and offshore extent. Management zone boundaries affected Stonington, Vinalhaven, Tenants Harbor, Spruce Head, New Harbor, and Long Island fishing areas to varying degrees in most seasons. Unofficial or territorial boundaries were assumed to have affected all areas, but some more obviously than others. Among these were Stonington, Tenants Harbor, Port Clyde, Metinic, Round Pond, New Harbor, Cousins Island, and Harpswell.

Discussion

As seen in the zone-by-zone comparison, territorial boundaries followed the two general types (nucleated and perimeter-defended) identified by Acheson (1988). I have not labeled all harbors as one type or the other because the type may not be inferred in all cases. There was considerable variation in how strictly the territorial boundaries were observed. Mixed fishing seems to be more tolerated in the eastern part of the state, while from the Penobscot Bay to Cape Elizabeth, boundaries seem to be more defined. The Mount Desert Island area showed considerable overlap in the inshore fishing areas. Lobstermen from Bar Harbor, Seal Island, and Southwest Harbor fish in fairly close proximity to one another throughout the year (Figures 4.1., 4.2., 4.3.). Stonington lobstermen fish near this area and possibly in the Milbridge area. These may be nucleated territories with boundaries observed only near harbor entrances. Personal interviews would be necessary to determine the accuracy of this information and reasons for these fishing patterns.

The Stonington and Isle au Haut boundary line is quite sharp (possibly perimeter-defended by Isle au Haut fishermen) as evidenced by the lack of any Stonington fishing activity on the west side of Isle au Haut (Figures 4.4., 4.6., and 4.7.). This boundary is apparently shifting with increased pressure from Stonington fishermen (Acheson, 1988; Greenlaw, 2002). It would be interesting to observe whether the Stonington logbook users push this boundary further or if they will respect historical fishing areas. There most likely are other lobstermen who are more aggressive in pushing this boundary.

Perhaps the most distinctly isolated fishing areas are represented in zone D. While data for all areas were not available in all of the time periods examined, comparisons among seasons revealed several patterns. Tenants Harbor and Port Clyde data were quite separate from each other (Figures 4.9. through 4.11.), almost as if a buffer zone exists between the fishermen who contributed data. Fishermen from these harbors are known to defend their territories vigorously (Acheson, 1988). The Tenants Harbor data do not encroach on the area around Metinic, representing a perimeter defended area, and a third boundary is an apparent division with Spruce Head (Figure 4.10.). The "empty" areas between the polygons may simply be there because data were not collected by the respective fishermen in those areas. Another possibility is that other fishermen from the two harbors or even another harbor typically occupy that space. Some of the bottom also may not be fishable. The productive Muscle Ridge Channel is part of the space between Tenants Harbor and Spruce Head, and lobstermen undoubtedly place traps there. The data from Tenants Harbor located within the zone C line during the August to December 2001 season (Figure 4.10.) may be there because it is in federal waters and the trap limits are the same for the two zones.

New Harbor and Round Pond fishermen are known to participate in mixed fishing outside of their harbors (Acheson, 1988). The data from these two harbors were unfortunately not concurrent, but in comparing the three maps (Figures 4.9. through 4.11.), the Round Pond fishing area is almost completely within the area New Harbor data appears. The Round Pond data is several miles from shore, so perhaps the perimeter of the New Harbor defended area is closer to shore, and the offshore areas are fished by both harbor gangs.

The Harpswell and Cousins Island areas were the only examples in which we have evidence of territoriality in zone F (Figures 4.12., 4.14., and 4.15.). The Cousins Island area seems to be a perimeter-defended area that is shared with the other Casco Bay islands such as Long Island (Figure 4.15.) against the peninsula of Harpswell to the east of Cousins. Very little overlap, if any, occurs between these two areas. Space is limited in terms of deeper water, and productive bottom can occur in many different areas throughout the summer and fall (Hillman, 2003). Lobstermen may have to travel more than a few miles offshore to find deeper water when lobsters start to move away from shallower areas.

Territoriality among harbor gangs was shown to have at least partially structured the fishing areas observed through Thistle Marine data. Both nucleated and perimeter defended areas were evidenced by the data, with the least boundary interaction (as well as the least fishing) apparently occurring in the December to March season. Comparison of these data with earlier maps may allow us to draw conclusions about the permanence of the individual boundaries as well as the forms of boundaries observed.

Official zone boundaries also place limits on the distribution of fishing effort. This boundary type is much newer than the unofficial, territorial boundary, and it is not flexible. Therefore, restructuring of the territorial boundaries may have occurred in recent years due to disruption of historical fishing areas, such as the existence of a buffer zone between zones D and E (Acheson, et al., 2000; Acheson and Brewer, 2003). In addition, the trap limits that came along with the zone boundaries may have played a part in the level of territoriality experienced by many harbor gangs. Though there are most likely just as many traps in the water as there were before the limits were imposed, the owners of those traps have changed. These changes have increased the complexity of the fishery in many ways, not the least of which is the issue of harbor territories.

Understanding the changes in where and how lobstermen fish is vitally important to the management and economics of the fishery. A dynamic fishery can not be treated as a temporally and spatially homogenous unit. Local stock depletion can result from a misunderstood local fishery, and assessment of economic investment and cost of effort will be inaccurate if homogeneity is assumed. The social impacts of these changes are also important to understand, and subsequent studies using Thistle Marine data will shed more light on the differences (and similarities) between historic and current data concerning territories. Conflict over boundary changes and shifts in effort affect the social interactions of harbor gangs (Acheson, 1975; 1981; 1988).

More data collected by more fishermen are needed to fully represent the current status of harbor fishing areas. Thistle Marine data have already contributed a great deal of information concerning the distribution of fishing effort and observance of territorial boundaries in all fishing seasons, information which previously existed only for certain parts of the year and on just a portion of the traps fished by one lobsterman. However, it is also important to note that this information is only available for a few harbors and is not necessarily representative of all territories and harbor gangs. Thus the spatial and temporal extent of the data need to be increased to determine if patterns observed in this study are indicative of current fishing behavior exhibited among harbor gangs in the Gulf of Maine. Regular recording of trip data will enhance and strengthen the results of future studies using electronic logbook data. Individual surveys are also needed to ground-truth the apparent boundaries seen in the data, and to obtain permission to use the data as public information.

Conclusions

This study has provided additional evidence for the continued existence of territoriality in the Maine lobster fishery, and more specifically of the two types of territories described in the literature on fishing territories (Acheson, 1988). The informal territories of some of the harbors along the Maine coast were observed using Thistle Marine data and GIS. The territorial boundaries observed from Mount Desert Island to the east may be relatively flexible with a good deal of mixed fishing occurring. In contrast, the boundaries we have evidence of from the east side of the Penobscot Bay to Cape Elizabeth seemed to be more tightly enforced with relatively less mixed fishing occurring. The impacts of state-imposed boundaries were also documented through the observations of trap distribution. This information adds to the already considerable body of literature on territories, fishing rights, and informal institutions.

Chapter 5

GENERAL OVERVIEWS, CONCLUSIONS, RECOMMENDATIONS, AND DISCUSSIONS

Management and Monitoring of the Maine American Lobster Fishery

Current monitoring programs run by the Maine Department of Marine Resources adequately describe the major aspects or characteristics of the American lobster fishery along the coast of Maine. The port sampling program has been in place since 1967, and it best describes the entire coast as a unit in terms of catch, effort, and biological characteristics. The sea sampling program was started more recently in 1985. The expansion of effort in the sea sampling program since 1998 has yielded finer scale data in terms of spatial comparison and area specific catch, effort, and biological data. Both programs produce sufficient quantity and quality of data for their purposes.

The spatially-explicit data collected by the Thistle Marine electronic logbook permitted detailed spatial analyses of the fishery. Such analyses can provide information on spatial dynamics of the fishery, thus improving our interpretations of fishery-dependent data. Because analytical methods for analyzing these data were insufficient, we explored and developed several spatial statistical approaches in this project to fully utilize these data. Lobster fishery managers should find the potential of this program interesting and useful in the development of fishery assessment and management tools that are spatially explicit and in the interpretation of the fishery-dependent data (e.g., catch per unit of effort).

However, to reach the full potential of the sampling program and to provide an accurate spatial assessment of the fishery to management, the program needs to be expanded to cover more areas and more lobster boats. The methods developed in this study could more effectively assess the fishery if the volume and consistency (quantity and quality) of sampling were increased. The success of the sea sampling program in response to the increase in quantity and quality of data collected should encourage a similar increase in the Thistle Marine logbook sampling program.

While sea sampling provides good management area-specific data, Thistle Marine data provides the potential of smaller temporal and spatial scale coverage, and therefore a more accurate and precise depiction of the fishery. This picture could be scaled up to any temporal or spatial resolution desired, given proper, unbiased sampling of the fishery. If logbook data were collected by an adequate cross-section of the fishery (with the understanding that there are no typical fishermen), catch and effort data should track well with the sea and port sampling programs at their respective spatial and temporal scales.

Because of our conclusion that both sea and port sampling programs adequately represent the fishery based partially on spatial and temporal CPUE trends, a similar comparison might be made with logbook data. Market category frequencies (as a proxy for length frequencies) could be compared between logbook and sea sampling data. Results of these comparisons could serve as a test for adequate sample size of logbook data. If CPUE and catch frequency from both sampling programs were spatially and temporally similar, we could have confidence that electronic logbook data were representative of the fishery.

Upon establishing whether the electronic logbook data are representative of the fishery, spatial analysis tools and methods could be employed with more confidence. However, the demands of these tools and methods on the data are greater than catch, effort, and biological analyses. Regularity in space and time of the data are often requirements for more advanced, second order spatial analyses. Less restrictive tools and analyses would allow flexibility in which data could be used and at what scale analyses are conducted. Often unintended results come from the information provided by spatial analysis tools, and the analyst needs to be aware of the potential of the analysis apart from the intended purpose (such as the test for spatial randomness providing inter-trap distances). The tools can also be misused and the results may indicate trends that do not exist in reality. The analyst needs to be well acquainted with the data, the sampling methods, and limitations and assumptions associated with the spatial statistical methods. Spatial data need to be visualized at several different temporal and spatial scales, and the appropriate scale identified to better understand trends in the data.

Aside from the restrictions and precautions necessary when using spatial analysis tools, there are many applications possible to Thistle Marine data. While this study did not realize the full potential of spatial analysis with the data, some methods were explored and developed. These methods should be useful to further work. More work is vitally important to understand the variations in how fishermen pursue lobsters. This understanding is important for reliable interpretation of fishery-dependent data in lobster assessment and management

Current stock assessment uses limited catch information from the fishery for input data. This is not a satisfactory method in the opinion of many scientists, and therefore efforts are underway to use spatially explicit sampling data for the official stock assessment of the lobster population. In order for new methods of stock assessment to be developed based on fishery sampling, the spatial dynamics of the fishery and behavior of fishermen in response to changes in the fishery must be understood. Fishermen are experts at locating lobsters and tracking their movements over short time intervals, so by understanding their movements, local stock dynamics and fleet dynamics can be better understood. The variations among these local stocks can be incorporated into models so that information is not averaged out, but instead serves to construct a more reliable and accurate assessment of the stock as a whole.

Variation in Local Fisheries

Lobsters are pursued by many fishermen in many different ways. A fisherman from Portland will fish quite differently than a fisherman from Vinalhaven, and a part-timer will not behave like a full-time fisherman. The variation among fishermen even within one harbor gang makes it tempting for managers to treat the fishery as one homogeneous unit. This approach would not provide satisfactory results for either fishermen or managers because by ignoring variation, impacts to individual fishermen and local stocks would be ignored, which may cause and have a negative effect on the fishery as a whole. Therefore, categorical differences must be addressed in fishery characteristics such as number of traps fished, geographical area occupied, depth fished, movement over time, fishing intensity or density of traps, and economic situation. Factors such as these separate individual fishermen, harbors, and zones throughout the coast of Maine. By understanding these factors, managers and scientists would be better informed in assessing the lobster stock and making management decisions.

It is important to understand the scale at which variation occurs. In several parts of this study, we found that as the scale was reduced in space and time in examining smaller parts of an overall pattern, some trends disappeared while others appeared. Trap location intensity is a good example of this because as the time frame and the area sampled were reduced, intensity patterns disappeared, became fragmented, and shifted. Essentially a picture of a chaotic system emerged with no predictable pattern emerging. It is this chaotic system that managers are unable to deal with except by viewing the fishery at a scale which can effectively remove the variation.

Management Implications

The extension of zone boundaries into federal waters has had some perhaps unintended consequences. Lobstermen now can not fish in the federal waters of an adjacent zone that has a more restrictive trap limit. As seen in the lobster territories study, some lobstermen fished in the federal waters of other zones in 2001. This is the situation in Zone F where lobstermen who in the past had fished in Zone E federal waters could not because of Zone E's more restrictive trap limit. Currently, Zone G is considering lowering their trap limit by one trap so that Zone F lobstermen can not fish in the federal or state waters of Zone G. Lobstermen in Casco Bay would be boxed in and their income limited (Hillman, 2003).

Management rules to limit movement are bound to encounter problems. The distance required to reach productive lobster bottom varies widely throughout the year and along the coast. Lobstermen in Penobscot Bay have deep, productive bottom a short steam from their harbors while deep, productive bottom in the western part of the coast requires a ten-mile steam in many areas. Productive areas fluctuate over the seasons and from year to year, so that limiting areas really limits the income of fishermen. Maps of trap location intensity depict this seasonal variation in the Stonington area, where concentrations of traps change from month to month.

Area restrictions also may influence inter-trap distances. We found that over a month's time, most traps are placed quite close to the last place they were set or near to other traps, usually 100 meters or less. With fewer areas to fish, trap placement patterns might change in several ways. One change might be that an individual's traps would be placed further apart as competition for space increased, and less space is available for each fisherman. The individual cost to each fisherman would increase as his search time for available, productive bottom increased. Additional cost would be incurred because of inevitable gear tangles caused by congested areas. This already occurs in the summer season, but this problem would likely extend into other seasons of the year.

Another pattern might emerge where a large number of traps would be placed in one area by a fisherman to reserve space. His catch per trap would most likely drop, but all his traps would be in a productive area and he would not have to go far to haul them. Essentially his traps would be inefficient while his movements would possibly be more efficient. Efficiency would most likely be affected in any management scheme that tried to limit areas beyond the scale of the lobster management zone.

Future Uses of Fishery Dependent Data

Most fishermen focus on what they are catching in their traps and what it costs them to fish. As small business owners in competition with other small businesses, the bottom line is what matters. Managers need to consider this and calculate the economic costs of their decisions. Equipment and travel cost calculation can be aided by using fishing intensity maps and inter-trap distances coupled with catch and effort data. Distance traveled from the harbor and amount of area fished are other useful pieces of information for economic analysis.

Ecological purposes can be served using fishery dependent data as well. Catch and effort data can be compared with independent surveys and research projects to develop population abundance indices. Fishing intensity can be compared with demographic hotspots (Steneck and Wilson, 2001) and larval settlement patterns to develop an understanding of ecological links to the fishery.

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APPENDICES

Appendix A. Arc View Procedure To Prepare Spatial Data For The Moving Window Model

Converting Decimal Degree Data to UTM Data

ESRI's ArcView 3.2a was used to visualize the data. The data was imported using the add database connection routine in the project window.

1. Now open up view 1 from the project view window, select view and add event theme.
2. The popup will read the table name, x field as longitude and the y field as latitude. Click ok and the table will open into the view, with a blue bar oscillating at the bottom.
3. Click the square theme button to display the data in the view. Click the name of the theme to select the theme.
4. Click the theme drop down and select convert to shapefile.
5. Select the folder and the name of the shapefile that will be created.
6. Shapefile is created. Add to the theme to make sure it overlays the database table theme. Select the theme and display it.
7. Now click the file menu and select arcview projection utility (or go under the program list in the start menu and select the projection utility from the arcview list
8. The utility will take a bit to open. Browse for the shapefile just created and select it. Click next.
9. Select the geographic coordinate system type, GCS North American 1983, degree units.

10. Showing advanced options, Parameters will be set to the Greenwich meridian, and geotransformation will be unset. Click next and say ok or yes to saving the coordinate system info with the input shapefile. This identifies the coordinate system of the thistle data.
11. The output shapefile should be projection, using the WGS 1984 utm zone 19 project with units in meters. Accept the default parameters, geotransformation will be unset, and ellipsoid will be as is. Click next. Select the destination and file name for the projected shapefile. The projection information will be displayed. Click finish.
12. Wait a moment and the projection process window will open. It will say when it is finished. The option to add the new shapefile to the project will be offered if the utility was opened from within the program.
13. Add the shapefile as a theme to the view. Select the theme and zoom to it. The other themes will disappear from the view, and the coordinates will change to utm's (x~500,000, y~4,800,000). Close the project.

Retrieving UTM coordinates into table format

1. Use the msdos program shp2sdo (shape to oracle spatial data). Open it in the same location as the projected shapefile. Type in the name of the shapefile without the .shp at the end. It will say how many points are in the file. The next line will ask what the name of the output file should be. Defaults are in brackets[]. Name the file something different and accept all other default

values. When the bounds line appears, write down the x and y coordinates which are helpful in the moving window settings.

2. Enter all the way through and after the processing messages, the window will close automatically after processing. Don't close it manually or the file may not be complete.
3. Open Excel, open the .dat file that was named as the output file. A text delimiting window will open. Select delimited data type, click next, select other and enter "|" (the key above enter,shift) and click next. Accept the general format options and click finish. The file will open in excel with columns for each entry type.
4. Save this as a text file.
5. Now delete all columns except number of lobster, number of traps and the x and y locations. Be sure that the x and y locations have the number of decimals desired (none or maybe 1 or 2 – one meter is sufficient for the purpose of this study). I chose no decimals the second time around. I didn't format at all the first, so the utms had two to four decimals, depending on how they were saved I guess.
6. Save this file as obs.txt.

Appendix B. Using The Moving Window Model

1. Move obs.txt into the same folder as lobstermeans.exe
2. Open lobstermeans (version number 1 or 2; 2 has the additional option of selecting a reference area such as 100 square meters or square kilometers etc. Also there are two additional output files which calculated different spatial means)
3. Enter 1 to open obs.txt
4. Enter the lower left x coordinate of the study area (475000 – no commas) and the lower left y coordinate (4840000).
5. The extent of the area will depend on whether you are breaking it up into small areas or doing the whole area. Initially enter x = 100000 and y=75000. This will give a 100,000 meter by 75,000 meter area.
6. Then enter the output resolution. This will vary depending on how small or large a scale you want to view the data. Putting in too small a resolution (say 10) will cause the program to shut down if the study area is large (as it is above). 100 to 500 seems to work well, though calculation takes a lot longer the smaller the resolution. The resolution is the side of one pixel (in this case in meters). The pixels will be in square meters (500 X 500 = 250,000 square meter pixels; 100X100 = 10,000 square meter pixels). This basically defines how many rows and columns are in the grid over which the window moves.
7. Enter the size of one-half the side of the moving window. Entering 5 will produce an 11 pixel by 11 pixel window with one pixel in the center. If the resolution is set to 100, the window will average an area of 1,100 m by 1,100 m or 1.2 square

kilometers. It moves one pixel length for each individual calculation, so the number of calculations increases with 1) increased study area size, 2) increased resolution (smaller pixels), and 3) decreased window size.

8. The next prompt will be for the reference area. This means what number to multiply each average by. Since the averages are in square meters, multiplying them by 1,000,000 will produce averages in square kilometers. For instance number of lobsters per square kilometer or number of traps per square kilometer.
9. Now the program may run for less than a minute to more than 30 minutes, depending on the settings. When running version 1, three ascii files will be produced. Mlob, mtrap, and mloc (.asc). Mlob is number of lobsters per window area (in square meters), mtrap is number of traps per window area, and mloc is number of locations per window area.
10. Running version 2 will produce mlob, mlob2, mtrap, mtrap2, and mloc. Mlob is number of lobsters per number of locations, mlob2 is number of lobsters per window area times the reference area (can be square meters and greater), mtrap is number of traps per number of locations, mtrap2 is number of traps per window area times the reference area, and mloc is number of locations per window area times reference area.
11. Now the ascii file that will be used in Arcview must be moved into a continuously named folder on c: drive (ie. "c:movingwindow"). A syntax error will appear after an attempt to save the grid file in Arcview if there are any spaces in any folder or file name.

Appendix C. Moving Window Model C++ Code

```
// biomass.cpp : calculates biomass of an arc ascii grid A based on constraints
//defined by an arc ascii grid B.
#include "stdafx.h"
#include "biomass.h"
#include <fstream.h>
#include "math.h"
#include "Matrix.h"
#include "Location.h"
#include <afxtempl.h>

#ifdef _DEBUG
#define new DEBUG_NEW
#undef THIS_FILE
static char THIS_FILE[] = __FILE__;
#endif

/////////////////////////////////////////////////////////////////////////////
// The one and only application object

CWinApp theApp;

//using namespace std;

int _tmain(int argc, TCHAR* argv[], TCHAR* envp[])
{
	int nRetCode = 0;

	// initialize MFC and print and error on failure
	if (!AfxWinInit(::GetModuleHandle(NULL), NULL, ::GetCommandLine(), 0))
	{
	// TODO: change error code to suit your needs
		cerr << _T("Fatal Error: MFC initialization failed") << endl;
		return nRetCode = 1;
	}
//////////////////////////////////////////////////////////////////////////////
//////// MY CODE
	ifstream inFile; // Input data file.
	ofstream outFile; // Output data file.
	CMatrix meanlobster, avglobster, meantraps, avgtraps, meanlocations;
	double llx, lly, extentx, extenty;
	double winllx, winlly, winurx, winury, winarea, refarea;
	int lobstercount, trapcount, locationcount;
	int intdummy = 0, i, j, k, nodata=-9999;
	int ncols, nrows;
```

```
int windowsize;
double outres, wincenterx, wincentery;
CList<CLocation,CLocation&> observations;
CLocation sample, temp;

cout << "Enter 1 to load observations (obs.txt):";
cin >> intdummy;
cout << "\n";


meanlobster.Empty();
meantraps.Empty();
meanlocations.Empty();
avglobster.Empty();
avgtraps.Empty();


inFile.open("obs.txt");
if(!inFile)

{
        cout << "Error opening file\n";
        return nRetCode;
}

while(inFile)
{
        inFile >> sample.lobster >> sample.traps >> sample.x >> sample.y;
        if (inFile) observations.AddTail(sample);
}


inFile.close();

cout << "Please enter the coordinates of the lower left corner: \n";
cout << "    x = ";
cin >> llx;
cout << "\n";
cout << "    y = ";
cin >> lly;
cout << "\n";
cout << "Please enter the extent of the area: \n";
cout << " in x = ";
cin >> extentx;
cout << "\n";
cout << " in y = ";
```

```
cin >> extenty;
cout << "\n";
cout << "Please enter the desired output resolution: \n";
cout << "\n";
cout << "  res = ";
cin >> outres;
cout << "\n";

ncols = int(extentx/outres);
nrows = int(extenty/outres);

meanlobster.SetMatrixSize(CSize (ncols,nrows));
meantraps.SetMatrixSize(CSize (ncols,nrows));
meanlocations.SetMatrixSize(CSize (ncols,nrows));
avglobster.SetMatrixSize(CSize (ncols,nrows));
avgtraps.SetMatrixSize(CSize (ncols,nrows));

cout << "Please enter the size of the moving window (half the side in pixel): \n";
cin >> windowsize;
cout << "\n";

winarea = ((2*windowsize*outres + outres) * (2*windowsize*outres + outres));

cout << "Please enter the size of the reference area: \n";
cin >> refarea;
cout << "\n";


for (i=0;i<nrows;i++)
{
        for (j=0;j<ncols;j++)
        {
                meanlobster.SetAt(CPoint (j,i),nodata);
                meantraps.SetAt (CPoint (j,i),nodata);
                meanlocations.SetAt (CPoint (j,i),nodata);
        }
}


POSITION pos = observations.GetHeadPosition();

for (i=windowsize;i<(nrows-windowsize);i++)
{
        for (j=windowsize;j<(ncols-windowsize);j++)
        {
                lobstercount = 0;
```

```
trapcount = 0;
locationcount = 0;

wincenterx = llx + j*outres + 0.5*outres;
wincentery = lly + nrows*outres - (i*outres + 0.5*outres);
winllx = wincenterx - (0.5*outres + windowsize*outres);
winlly = wincentery - (0.5*outres + windowsize*outres);
winurx = wincenterx + (0.5*outres + windowsize*outres);
winury = wincentery + (0.5*outres + windowsize*outres);

pos = observations.GetHeadPosition();

for (k=0;k<observations.GetCount();k++)
{
        temp = observations.GetNext(pos);

        if ((temp.x >= winllx) && (temp.x < winurx) && (temp.y
>= winlly) && (temp.y < winury))
        {
                lobstercount = lobstercount + temp.lobster;
                trapcount = trapcount + temp.traps;
                locationcount++;
                cout << "test\n";
        }
}


if (locationcount == 0)
{
        meanlobster.SetAt(CPoint (j,i),(nodata));
        meantraps.SetAt (CPoint (j,i),(nodata));
}

else
{
        meanlobster.SetAt(CPoint
(j,i),(lobstercount/locationcount));
        meantraps.SetAt (CPoint (j,i),(trapcount/locationcount));
}


avglobster.SetAt(CPoint (j,i),(lobstercount/winarea*refarea));
        avgtraps.SetAt (CPoint (j,i),(trapcount/winarea*refarea));
meanlocations.SetAt (CPoint
(j,i),(locationcount/winarea*refarea));
```

```
		}
	}

	outFile.open("mlob.asc");
	if(!outFile)

	{
		cout << "Error opening file\n";

		return nRetCode;
	}
	outFile << "NCOLS " << ncols << "\n";
	outFile << "NROWS " << nrows << "\n";
	outFile << "XLLCORNER " << llx << "\n";
	outFile << "YLLCORNER " << lly << "\n";
	outFile << "CELLSIZE " << outres << "\n";
	outFile << "NODATA_VALUE " << nodata << "\n";
	for (i=0;i<nrows;i++)
	{
		for (j=0;j<ncols;j++)
		{
			outFile << meanlobster.GetAt(CPoint (j,i));
			outFile << " ";
		}

		outFile << "\n";
	}
	outFile.close();

	outFile.open("mlob2.asc");
	if(!outFile)

	{
		cout << "Error opening file\n";
		return nRetCode;
	}
	outFile << "NCOLS " << ncols << "\n";
	outFile << "NROWS " << nrows << "\n";
	outFile << "XLLCORNER " << llx << "\n";
	outFile << "YLLCORNER " << lly << "\n";
	outFile << "CELLSIZE " << outres << "\n";
	outFile << "NODATA_VALUE " << nodata << "\n";
	for (i=0;i<nrows;i++)
	{
		for (j=0;j<ncols;j++)
```

```
        {
                outFile << avglobster.GetAt(CPoint (j,i));
                outFile << " ";
        }

        outFile << "\n";
}
outFile.close();

outFile.open("mtrap.asc");
if(!outFile)

{
        cout << "Error opening file\n";
        return nRetCode;
}
outFile << "NCOLS " << ncols << "\n";
outFile << "NROWS " << nrows << "\n";
outFile << "XLLCORNER " << llx << "\n";
outFile << "YLLCORNER " << lly << "\n";
outFile << "CELLSIZE " << outres << "\n";
outFile << "NODATA_VALUE " << nodata << "\n";
for (i=0;i<nrows;i++)
{
        for (j=0;j<ncols;j++)
        {
                outFile << meantraps.GetAt(CPoint (j,i));
                outFile << " ";
        }

        outFile << "\n";
}
outFile.close();

outFile.open("mtrap2.asc");
if(!outFile)

{
        cout << "Error opening file\n";
        return nRetCode;
}
outFile << "NCOLS " << ncols << "\n";
outFile << "NROWS " << nrows << "\n";
outFile << "XLLCORNER " << llx << "\n";
outFile << "YLLCORNER " << lly << "\n";
outFile << "CELLSIZE " << outres << "\n";
```

```
        outFile << "NODATA_VALUE " << nodata << "\n";
        for (i=0;i<nrows;i++)
        {
                for (j=0;j<ncols;j++)
                {
                        outFile << avgtraps.GetAt(CPoint (j,i));
                        outFile << " ";
                }

                outFile << "\n";
        }
        outFile.close();

        outFile.open("mloc.asc");
        if(!outFile)

        {
                cout << "Error opening file\n";
                return nRetCode;
        }
        outFile << "NCOLS " << ncols << "\n";
        outFile << "NROWS " << nrows << "\n";
        outFile << "XLLCORNER " << llx << "\n";
        outFile << "YLLCORNER " << lly << "\n";
        outFile << "CELLSIZE " << outres << "\n";
        outFile << "NODATA_VALUE " << nodata << "\n";
        for (i=0;i<nrows;i++)
        {
                for (j=0;j<ncols;j++)
                {
                        outFile << meanlocations.GetAt(CPoint (j,i));
                        outFile << " ";
                }

                outFile << "\n";
        }
        outFile.close();


        cout << "The rasters are stored in the files mlob.asc, mtrap.asc, mloc.asc \n";
        cout << "enter 1 to finish\n";
        cin >> intdummy;

        return nRetCode;
}
```

Appendix D. Viewing Moving Window Results in Arc View

1. Open a project with a new view, select the file menu and click import data source.
2. Select Ascii raster and click ok. Open the file that is to be viewed.
3. Save the grid file in the run folder so it doesn't get mixed up with all the other runs. This should be in the folder under c: drive with the run files.
4. Don't create cell values as integers. Some values are only decimals.
5. Add the theme to the view. Double click the theme box to edit the data classes.
6. Click classify. Set 10 classes at 4-6 decimals, depending on the file. Select the color intervals (blue to red dichromatic). Apply.

BIOGRAPHY OF THE AUTHOR

Kevin Scheirer was born in Concord, New Hampshire on June 12, 1973, to Robert and Sharon Scheirer. He was raised in Pembroke, New Hampshire, attending and graduating from the Concord Christian Schools in 1992. He attended the University of New Hampshire in Durham and graduated in 1996 with a Bachelor of Science degree in Marine and Freshwater Biology. His undergraduate research was focused on saltmarsh restoration while working at the Jackson Estuarine Laboratory where he continued working the summer after graduation.

He continued to reside in the seacoast New Hampshire area while working for S.W.A.M.P., Inc. in 1997, and he pursued anadromous and inland fisheries interests with the U.S. Fish and Wildlife Service and the U.S. Forest Service from 1998 to 2000. In 1999, he was married to Carrie Anne Mason. Catherine Grace Scheirer was born in 2000, and Kevin decided to pursue his master's degree at the University of Maine in Orono. Starting in the winter of 2001, he joined Dr. Yong Chen's population dynamics lab while taking course work in the marine policy program. Kevin became a part-time student the summer of 2002, when he took a research position with the Gulf of Maine Research Institute in Portland, Maine. Kevin is a candidate for the Master of Science degree in Marine Policy from The University of Maine in December, 2003.